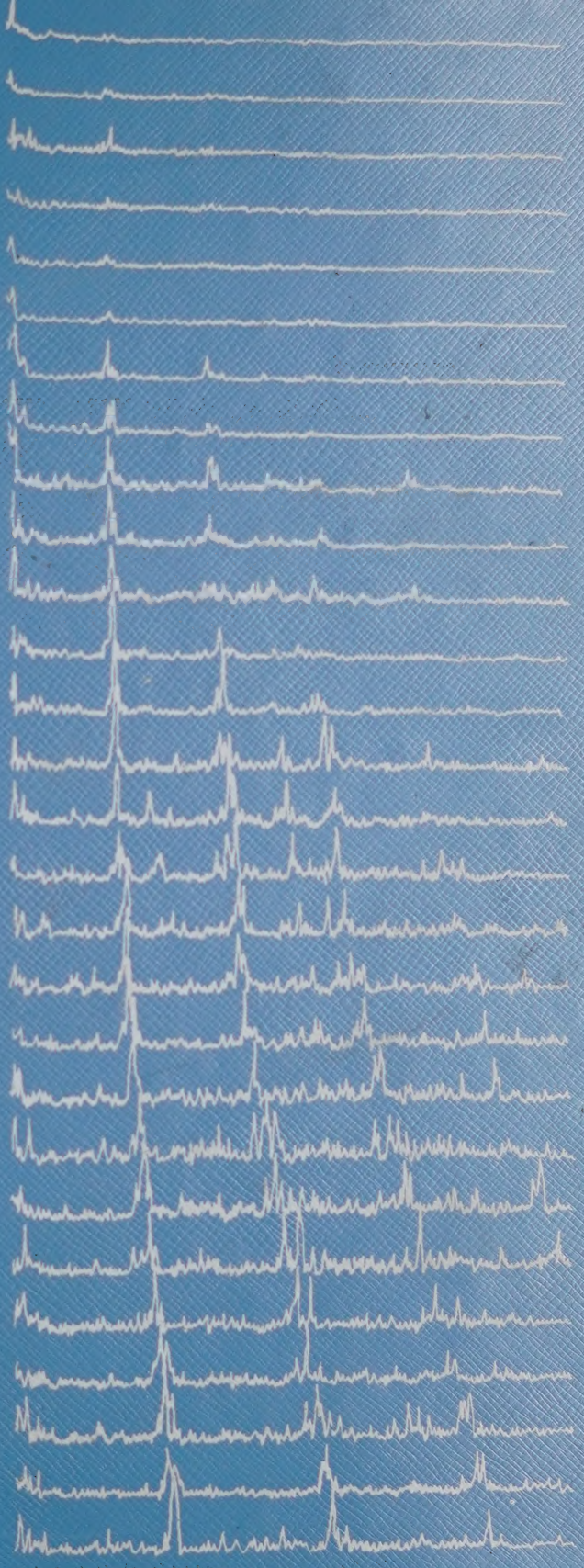
UBIQUITOUS® SIGNAL PROCESSING EQUIPMENT



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NICOLET SCIENTIFIC CORPORATION

Serial Number _____

Instruction Manual

for

MODEL 444

MINI-UBIQUITOUS®

FFT COMPUTING SPECTRUM ANALYZER

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manufacturers of UBIQUITOUS® instruments

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Sincerely,

Henry J. Bickel
President

INSTRUCTION MANUAL NOTICE

Every effort has been made by the Engineering and Service Departments of Nicolet Scientific Corporation to present accurate, helpful, and readily understood instructions in this manual. Our goal is to assist you in the efficient operation and maintenance of your precision instrument. The following information will facilitate your use of this publication.

CORRECTIONS:

Sometimes, changes in text or descriptions of circuit design changes cannot be incorporated in the printed manual (and its schematic diagrams). In this event, we provide you with the latest data on the colored pages in this manual following this page. These colored pages cover corrections to the text or to certain of the schematic diagrams, and must be read for the manual to properly reflect the equipment you received.

DATA COVERING OPTIONAL FEATURES AND SYSTEM CONFIGURATIONS:

Data covering certain optional features of our equipment, or special system configurations are provided in the text. If you have not ordered these options, the corresponding section of the manual does not apply to the equipment you received.

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SPECIAL INSTRUCTIONS

SPECIAL INSTRUCTIONS

WARNING

CONCERNING SAFE OPERATION OF ELECTRICAL EQUIPMENT:

1. This equipment is supplied with a detachable, rubber-covered electrical ac power line cord. One termination of the cord is a standard three-contact female connector for mating the AC INPUT receptacle on the instrument's rear panel. The other termination is a 3-prong male connector for mating a power source outlet, with one of the power source terminals at ground potential. THIS EQUIPMENT SHOULD NEVER BE OPERATED UNLESS IT IS PROPERLY GROUNDED.

2. If you use a 2-prong to 3-prong adapter for mating to your power source outlet, make sure that the pigtail lead (the grounding strap which is provided on the 2-prong adapter) is securely grounded. FAILURE TO FOLLOW THIS WARNING MAY RESULT IN ELECTRICAL SHOCK TO OPERATING AND MAINTENANCE PERSONNEL.

3. Nominal 115-volt or 220-volt ac potentials are present on the terminals of the front panel POWER switch and on the rear panel ac POWER INPUT connector and line protective fuse. Nominal 115-volt or 220-volt ac potentials also exist on the terminal strip of the self-contained power supply module and at various electrical terminals within the power supply module. ALWAYS EXERCISE EXTREME CARE WHEN WORKING IN OR NEAR THESE AREAS TO AVOID SEVERE ELECTRICAL SHOCK!

4. Lethal dc voltages are present within all Nicolet Scientific Corp. manufactured equipment utilizing switching type power supplies and CRT displays. This equipment should only be serviced by TRAINED PERSONNEL using extreme care to avoid severe electrical shock.

CONCERNING COVER REMOVAL:

To properly remove cover, shut off POWER and unlock the two fasteners on the side of the unit. Place fingers behind cover by screws. Lift the bottom end up and out in one motion.

FIGURE 1-1. MODEL 444 MINI-UBIQUITOUS®
SPECTRUM ANALYZER

SECTION I

INTRODUCTION

1-1. Scope of Manual

This manual covers the description, specifications, and operation, as well as the block diagram description of the MINI-UBIQUITOUS® 444 portable, Real Time Spectrum Analyzer. Also included is a review section useful to the operator. This section describes how to obtain meaningful information from the display by use of the cursor and calibration constant. Setup information for calibration in terms of input voltage, engineering units, and power spectral density are also provided.

The 444 combines the precision of all digital computation of a 400 line spectrum with the usefulness of an internally generated graticule on a built-in display and annotation on the display of all significant front panel settings. See Figure 1-1. The 444 also features sixteen frequency analysis ranges, transient capture mode, linear or logarithmic readout of horizontal and vertical axes, a vertical cursor for the readout of any single frequency element and its corresponding spectral value, uniform or Hanning weighting window, display of input time signal stored in the input buffer, and external sampling input.

The 444 contains a dual memory averager which can average up to 512 spectra in sum, difference, exponential or peak mode. The computational capability of the 444 permits addition, subtraction and ratio of the averager memory contents as well as direct visual comparison on a dual display. 1/3 and 1/1 octave display of averaged data is available as an option.

1-2. Organization of Manual

A. SECTION II covers the detailed specifications of the instrument.

B. SECTION III describes settings and operation of front and rear panel controls and indicators.

C. SECTION IV includes a checkout procedure using the internal TEST signal.

D. SECTION V describes aids to understanding and efficient utilization of the Model 444.

E. SECTION VI presents a description of the Model 444 system block diagram.

F. SECTION VII describes the user adjustments of the Model 444.

G. SECTION VIII describes the optional Expansion Plug-in.

H. SECTION IX covers the warranty applicable to the Model 444. Included are instructions for reshipment of the instrument to the factory, if the equipment is damaged in shipment, or malfunctions after receipt by the user.

I. SECTION X includes a set of schematic diagrams for this instrument, and is the concluding section of this manual.

SECTION II

SPECIFICATIONS

2-1. Display (on Built-in CRT)

A. Data: Repetitive readout of one of the following:

1. Time function, continuous or captured
2. Instantaneous spectrum of time functions
3. Averaged power spectrum A or B
4. Instantaneous spectrum and averaged power spectrum A (dual display)
5. Instantaneous spectrum and averaged power spectrum B (dual display)
6. Averaged power spectrum A and averaged power spectrum B (dual display)
7. Averaged power spectrum A plus averaged power spectrum B
8. Averaged power spectrum A minus averaged spectrum B, or B minus A
9. Averaged power spectrum A divided by averaged power spectrum B, or B divided by A

B. Electronic Graticule

Non-parallax rectangular graticule is generated; 10 marks on frequency axis for linear and 2 marks for log (at 1 and 2 decades below full scale); for single displays, 10 marks on amplitude axis for linear and 6 marks for log (at 10 dB intervals); for dual displays, twice as many amplitude marks are produced; for time, 8 marks for horizontal and $\pm$5 marks around zero center for vertical, top and bottom correspond to input amplitude full scale; rear panel switch removes graticule.

C. Annotation

For frequency displays, letters and numbers indicate input sensitivity in VRMS, frequency range, type of data, averaging mode, number of spectra averaged, data weighting, display

gain/attenuation, A-weighting on/off, mathematical calculation between averages, and 4-digit I.D. number; for time displays, full-scale input amplitude read as volts (zero to peak); horizontal time scale indicated by "SEC" and frequency scale by "HZ"; indicates origin frequency of expanded range in place of ID number (for 444-26 units) when in expanded mode; rear panel switch removes annotation.

D. Overall RMS Level

Shown on CRT for single spectrum displays (when cursor is on) for 400-line or 1/3 or 1/1-octave (-03 option).

E. Measurement Cursor

Cursor line moved left or right continuously or by single resolution element; intensified dot where line intersects spectrum (if intersection is within graticule); can be turned off.

F. Amplitude at Cursor

Referenced to 1 VRMS and read in units of V, V^2, or dB with respect to 1V (dBV); or read in engineering units directly by reference to any voltage from 1.00×10^{-9} to 999×10^{9} set by front panel GAIN controls; for dual spectra displays amplitudes of each and their ratio at cursor location.

G. Frequency at Cursor

For 400-line spectra, frequency reads in Hz (cycles/sec) or CPM (cycles/minute); also reads 1/3-octave band number if within bands 8 to 49 approximately 6 Hz to 94 kHz (-03 option not required); in ORDERS (external sampling), reads % FS; reads in annotation only when cursor is on.

H. Harmonic Marks

Additional intensified dots illuminate multiples of cursor setting on 400-line spectra; number of dots indicate harmonic number up to a maximum of 5 dots.

I. Display Scales

Lin or log, frequency or amplitude of spectrum

J. Display Gain

Linear - gain of 512 ("X512") to attenuation of 512 ("/512") in binary steps; log - gain of +50 dB to attenuation of -50 dB in 10 dB steps; set by front panel GAIN control.

2-2. Analysis Characteristics (400-line)

A. Frequency Ranges

1, 2, 5, 10, 20, 50, 100, 200, 500, 1,000, 2,000, 5,000, 10,000, 20,000, 50,000 and 100,000 Hz with built-in anti-aliasing filters (1, 2, 5 Hz ranges filtered with 10 Hz filter).

B. Number of Resolution Elements

400 per spectrum (generated from 1024 input time samples); nominal bandwidth, β, is 1/400 frequency range; noise bandwidth is 1.5β (1.0β when data automatically captured or armed).

C. Amplitude Linearity

$\pm$0.1 dB or $\pm$.05% of FS to 66 dB below FS, whichever is greater.

D. Frequency Accuracy and Stability

.01 percent of full scale without warmup.

E. Minimum Detectable Signal

70 dB below full scale typical, -75 dB with background subtraction.
60 dB below full scale in octave analysis mode.

F. Two-Tone Dynamic Range: Typically better than 66 dB.

G. Intermodulation Distortion: -70 dB typical.

H. Amplitude Measurement Stability

$\pm$.1 dB from 10° C to 50° C (50° F to 120° F).

I. Expansion Plug-In (Option -26)

Built-in translator provides one analyzer band of 10 Hz, 50 Hz, 100 Hz, 500 Hz, 1 kHz, 2 kHz, 10 kHz or 20 kHz wide positioned in 10 Hz steps to 100 kHz; extra plug-in cards provide additional ranges (except for 10 Hz which requires modification of basic unit); origin frequency indicated on display (in place of I.D. number).

2-3. Transient Data

A. Data Hold

Manual HOLD/REL button holds data in input memory or allows new data to enter; AUTO ARM (or remote signal) allows next signal over preset level to automatically actuate hold; in auto-hold, 1/8 of memory period before trigger can be viewed; polarity and amplitude of auto-hold triggering selected as $\pm$1/16, $\pm$1/8, $\pm$1/4, or $\pm$1/2 of full input amplitude, lights indicate data being held or unit is armed; one spectrum of held data can be transferred to averager A memory by pushing START A after capture.

B. Viewing Held Data

Time signal can be displayed and plotted; in automatic hold, trigger level indicated by brightened dot on CRT. (Time not displayed when in 1/3 octave or 1/1 octave mode with Option -03.)

C. Data Weighting

Weighting removed automatically in ARMED or when data captured (in AUTO position of rear panel switch), or can be manually controlled using rear panel switch.

D. Memory Period

Length of data stored in the input memory in seconds is 400/frequency range (Hz).

E. Automatic Transient Averaging

Rear panel jumper provides automatic arm, capture and averaging of a succession of input transients (not valid for 1/3 or 1/1-octave mode with Option -03).

2-4. Input Characteristics

A. Input Impedance: 100 kilohms

B. Input Coupling: AC (-3 dB at less than 0.5 Hz), DC

C. Test Signal

Sinewave at 64 percent of display, replacing input signal.

D. Input Amplitude Sensitivity

(Volts RMS Full Scale) 100 MV (-20 dB), 200 MV, 500MV, 1V (0 dB), 2V, 5V, and 10V (+20 dB). Maximum input DC plus AC component = ±50V referenced to ground.

E. Input Amplitude Monitor

Lights indicate peak signal levels - OVERLOAD, -6 dB (greater than 1/2 full scale), -12 dB (between 1/4 and 1/2 FS), -18 dB (between 1/8 and 1/4 FS), and -24 dB (between 1/16 and 1/8 FS); all lights below the signal level illuminated (in OVERLOAD, all lights are on).

F. Input Sampling

12-bit A/D conversion at 2.56 times maximum frequency of range selected on internal sampling (FREQ); external sampling input (ORDERS) sets frequency coverage at 1/2.56 of sampling rate. (Display in orders of rotation requires 2.56 pulses/revolution/order.)

G. Input Filters

Lowpass anti-aliasing filters matched to each range with an initial rolloff of 120 dB/octave (7-pole elliptic); 10-Hz filter on 1, 2 and 5 Hz ranges; frequency response ±0.5 dB (except ±1.0 dB on 100 kHz range).

H. Digital Input

External digital data can be loaded in 2's complement form directly into memory (through rear connector).

I. A-Weighting

Synthesized A-weighting can be applied to ranges of 5K and above for 400-line analysis, or any 1/3 and 1/1-octave ranges (with Option -03).

2-5. Averaging

A. Modes

SUM - power spectra are added (true power averaging)

DIFF - power spectra are subtracted linearly from the previous average (negative amplitudes clipped at display bottom but retained in memory).

EXPON - average changes in time as the signal spectrum changes (N sets exponential time constant); operation equivalent to a "leaking integrator".

PEAK - stores maximum spectrum amplitude at each frequency location during an averaging cycle, producing a profile of maxima.

B. Averaging Control

STOP A - manual stop of averaging in A memory

START A - resets number of measurements count, erases A averager memory (unless in DIFF mode), and starts averaging in A memory.

CONT (Continue) A - starts averaging a A memory without erase; in SUM, DIFF, or PEAK mode, if actual number of spectra averaged is equal to or greater than setting of N, resets count.

TRANSFER A→B - transfers the contents of memory A to memory B, either during averaging in A memory or after averaging has stopped. (400-line, or 1/3-octave with Option -03).

C. Number of Averager Memories

Two for 400-line spectra (plus two for 1/3-octave spectra with Option -03; 1/1-octave display derived from 1/3 octaves).

D. Number of Spectra Averaged - N

Determines time of averaging or time constant of exponential averaging; set from 1 to 512 in binary steps; in CONT, averaging continues until STOP button is pushed.

E. IN-PROCESS Light

Flashes to indicate averaging is taking place; flashes in EXPON until N is reached, then is lit continuously.

2-6. 1/3 or 1/1-OCTAVE ANALYSIS (Option -03)

Range Setting	Center Freq. Range (Hz)	(ANSI Std. 1/3-octave band numbers)		Time Per Anal. (sec)
1/3-oct.				
5k	6.3 - 5,000	(Band 8 - 37)		2.4
10k	12.5 - 10,000	(Band 11 - 40)		1.2
20k	25 - 20,000	(Band 14 - 43)	Type E	.8
50k	50 - 40,000	(Band 17 - 46)		.8
100k	100 - 80,000	(Band 20 - 49)		.8
1/1-oct.				
5k	8.0 - 4,000	(Band 9 - 36)		2.4
10k	16.0 - 8,000	(Band 12 - 39)		1.2
20k	31.5 - 16,000	(Band 15 - 42)	Type E	.8
50k	63 - 31,500	(Band 18 - 45)		.8
100k	125 - 63,000	(Band 21 - 48)		.8

A. Characteristics

1/3-octaves synthesized from narrow-band spectra; center frequencies, bandwidths, and effective rolloffs meet ANSI Class III standards; 1/1-octaves synthesized from 1/3-octave spectra.

B. Cursor Reading

Center frequency in Hz, 1/3-octave band number and amplitude; ratio at cursor in dual displays.

C. Dual Memories

Two additional averager memories store 1/3-octave spectra.

2-7. Output Characteristics

A. CRT Outputs

X, Y, Z outputs for external annotated display.

B. X-Y Plotting (without interruption of display)

X, Y and pen lift outputs for analog X-Y plotter; plots single spectrum or time function; ORIGIN (zero volts) and FULL SCALE buttons position pen at lower left and upper right of scale; for 400-line log frequency, ORIGIN is first resolution element; in AT CURS, X and Y outputs follow cursor horizontal and vertical position; during PLOT, cursor follows pen while full display is simultaneously produced on CRT; can plot averaged spectra in B memory while averaging is taking place in A.

C. Store CRT

Slows display to match storage oscilloscope (e.g., Tek 613); output for annotated plots using a Tek 4662 digital plotter or annotated display on a Tek 4000 series CRT terminals (required Option -07 RS232 interface); internal control selects one of the following when STORE CRT button is pushed: (1) start paper tape read, (2) output ASCII data for paper tape punch (control settings and amplitude spectrum or time, control settings and real/imaginary and spectrum or time), (3) output ASCII on RS232 (requires Option -07). Internal control also permits operation with Model 144 Digital Tape.

D. Digital Input/Output

16-bit parallel with 4-bit ID code.

E. Remote Control and Sense

Can sense all front panel switches and amplitude lights; can control all front panel switches; 8-bit parallel ASCII output (requires Option -07 HP for HP9800 series calculators, or Option -07 for RS232 ASCII interface).

2-8. Miscellaneous

A. Weight

19 kgm (42 pounds) nominal with typical plug-in.

B. Power

90 - 130 volts or 180 - 260 volts, 48 - 66 Hz, nominal 150 watts.

C. Size

32.6 cm (12-7/8 inches) high including feet and handle, 25.3 cm (10 inches) wide, 51.9 cm (20-7/16 inches) long including maximum front and rear protrusions.

D. Storage Temperature

-55°C to +85°C (-67°F to +185°F)

E. Operating Temperature

0°C to 55°C (+32°F to +130°F)

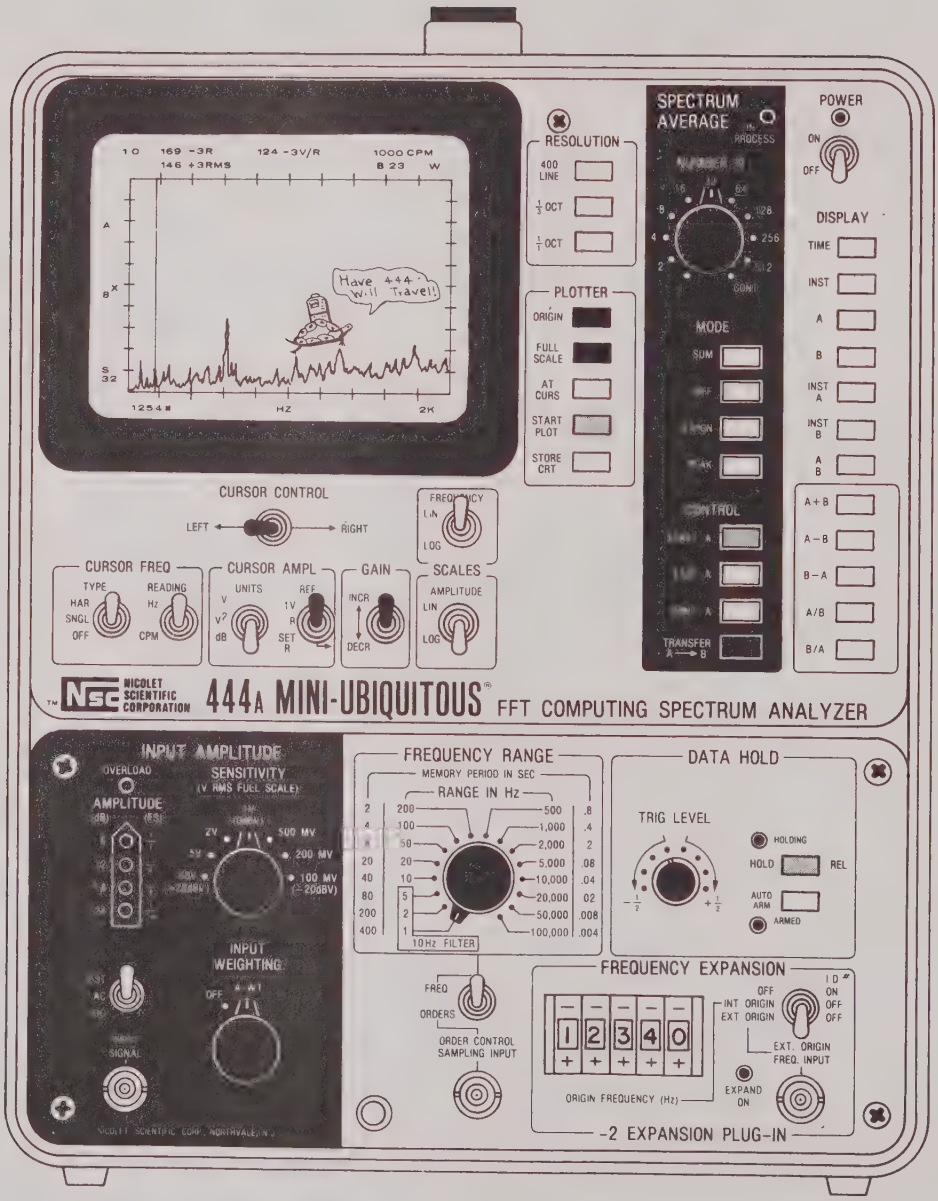


FIGURE 3-1. MODEL 444 MINI-UBIQUITOUS®
SPECTRUM ANALYZER, FRONT PANEL VIEW

SECTION III

FRONT AND REAR PANEL CONTROLS AND INDICATORS

3-1. Scope of This Section

This section of the instruction manual will describe the function of each control and indicator on the 444, as well as identify all connectors and corresponding signals that appear on the front and rear panels of the instrument.

3-2. INPUT AMPLITUDE - The Input Signal Controls

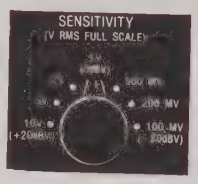
A. BNC Connector and TEST/INPUT SIGNAL Switch

The analog input signal to be analyzed is applied to the BNC connector. The signal is either AC or DC, coupled to the input circuits. Caution: The maximum input, DC plus AC component of the signal should not exceed ±50 volts. Do not apply line voltage to the input. Severe damage will result. The lower frequency 3 dB point due to AC coupling is less than 0.5 Hz.

When the TEST/INPUT SIGNAL switch is in the TEST position, an internally generated test signal is coupled into the

input circuits. The amplitude of the signal is approximately 100 millivolts rms, and its frequency is 64 percent of the selected FREQUENCY RANGE. When this switch is in the AC or DC position, the signal applied to the INPUT SIGNAL BNC connector is fed into the input circuits.

B. SENSITIVITY Switch



This seven position switch controls the input sensitivity over a 100 to 1 (40 dB) range. Full scale sensitivity of 100 mv, 200 mv, 500 mv, 1, 2, 5 and 10 volts are available with the 1V position designated as 0 dB. All voltage levels are root mean square (rms). The optimum setting of the SENSITIVITY switch will generally be determined by the OVERLOAD indicator. If the indicator is on, the input circuits are being overdriven and will generally yield spurious components in the spectrum. The optimum setting is the lowest input sensitivity without an overload indication.

C. INPUT WEIGHTING Switch

This two position rotary switch permits the selection of either normal (flat) or A-weighted input. A-weighting is in accordance with A.N.S.I. specification S1.4-1971 (specifications for sound level meters) type 1. The A-weighting is implemented by weighting (shaping) the spectrum output and will not affect the INPUT AMPLITUDE indicators or the OVERLOAD indicator. A-weighting will only function in the 5 kHz, 10 kHz, 20 kHz, and 50 kHz frequency ranges. In all other ranges it will automatically be turned off.

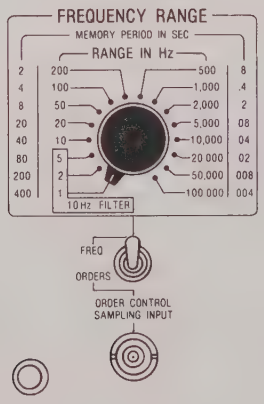
D. AMPLITUDE "LEDs"

This group of four LED (light emitting diode) indicators provides amplitude information on the input signal after the SENSITIVITY control. Illumination of any indicator signifies that the signal being analyzed is greater than the corresponding level. Thus, when the -18 dB indicator is on and the -12 dB indicator is off, the input signal is between -12 and -18 dB below full scale input. When a particular indicator in this group is on, all indicators below it must also be on. A-weighting which is done at the output of the Model 444 (in the frequency domain) does not affect the LEVEL indicators.

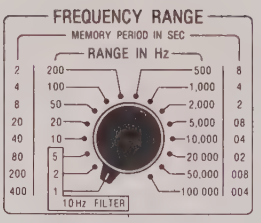
E. OVERLOAD "LED"

This indicator is on whenever the input signal amplitude causes limiting in the analog-to-digital converter, causing distortion in the output spectrum. When overload is detected, the indicator is held on for a pre-set time so that an overload condition, which occurs at intervals of approximately 0.5 second or less, will cause the indicator to remain on continuously.

3-3. FREQUENCY RANGE Controls



A. FREQUENCY RANGE Control



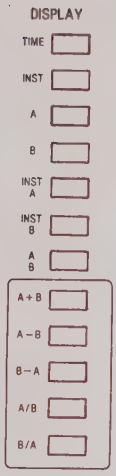
This control is used to select the cutoff frequency of the input lowpass filter and the internal sampling frequency (equal to 2.56 times the selected range). The switch contains two legends: one is the frequency RANGE IN HZ, and the other is the MEMORY PERIOD IN SEC. The latter reading is valid only when internal sampling is selected, or when the external sampling frequency is 2.56 times the FREQUENCY RANGE. The memory period is always equal to 1024 times the sampling period.

B. FREQ/ORDERS Switch and ORDER CONTROL SAMPLING INPUT Connector

The FREQ/ORDERS is a two position switch. In the FREQ position, sampling is controlled by a crystal oscillator in the 444 and the sampling frequency equals 2.56 times the FREQUENCY RANGE. In the ORDERS position, sampling is determined by an external input, which may be derived from the same mechanical device as the analog input signal to be processed, thereby tracking any frequency fluctuation created by speed variation of the mechanical device.

The ORDER CONTROL SAMPLING INPUT is a BNC connector, to which the external sampling frequency signal is applied. If the signal to be processed is derived from a rotating machine, the sampling input frequency may be the fundamental or any order of this fundamental. The ORDER CONTROL SAMPLING INPUT requires a minimum signal level of 1V peak to peak. The maximum frequency of the sampling input signal is 256 kHz (100 kHz FREQUENCY RANGE). The ORDER CONTROL SAMPLING INPUT signal is shaped by the internal waveshaping circuits of the 444, thereby allowing the use of any periodic waveform as an input. Maximum input signal is 10 volts peak to peak. Do not apply line voltage to this input. Severe damage will result.

3-4. DISPLAY - Mode Controls



This group of 12 interlocking switches is used to select the output to be displayed on the 444 CRT display. Each of the pushbuttons operates as follows:

1. TIME - When this button is depressed, the display consists of time data stored in the input buffer memory, from which the spectrum is derived. This data is always displayed with both linear vertical and linear horizontal scales.

2. INST - This switch position selects the display of the instantaneous spectrum data from the processed input data block. As the input data is updated via new samples, the spectrum derived is correspondingly updated. When the 444 is in HOLD, (see paragraph 3-10A), the INST display will exhibit no variation since it is derived from a fixed block of stored input data. The INST display can be presented on either linear or logarithmic vertical or horizontal axes.

3. A - In the A position, the display represents the averaging of successive, 50 percent redundant spectra in each of the 400 averager memory locations. Averaging is performed by calculation of the square of each spectral point prior to averaging. Upon completion of averaging, the square root of each averaged spectral point is displayed. The A averager data may be displayed in linear or logarithmic vertical and horizontal scales. Data stored in the A averager memory may be transferred to the B averager memory by means of the TRANSFER pushbutton described in paragraph 3-5C.4. There are separate A memories for narrowband and octave (optional) spectrum displays.

4. B - This switch position selects the display of the B averager memory. The B averager memory serves as a temporary storage memory where a spectrum may be stored for reference or for computation. Spectra cannot be accumulated directly in the B memory but must be transferred from the A memory via the TRANSFER control (paragraph 3-5C.4). Once a spectrum is stored in the B memory, it can only be erased by writing over it with another transfer operation.

There are also separate B averager memories for narrowband and octave (optional) spectrum displays.

5. $\frac{\text{INST}}{\text{A}}$ - This position of the display switch selects a dual display. The upper trace is the instantaneous spectrum and the lower trace is the averaged spectrum from the A averager memory.

6. $\frac{\text{INST}}{\text{B}}$ - This position like the previously described switch selects a dual display. The instantaneous spectrum will be displayed above the spectrum stored in the averager memory.

7. $\frac{\text{A}}{\text{B}}$ - This position selects a dual display with contents of averager memory A displayed above the contents of averager memory B.

8. A + B - When this position is selected, the arithmetic sum of the contents of averager memory A and averager memory B is computed and displayed. This computation does not change the contents of either memory and the summation is not stored.

9 and 10. A-B and B-A - These positions select the arithmetic difference of the averager A and B memory contents. As in the previously described mode setting, the averager memories are not altered, and the results of the computation are not stored. Negative results are not displayed but are forced to zero. Care in the selection of the A-B or B-A positions is required to minimize errors due to negative differences.

11 and 12. A/B and B/A - In these positions the ratios of the spectra contained in the A and B averager memories are computed. In the event that the denominator function goes to zero, the displayed result limits at full scale. Similarly, if the numerator function is zero, the result goes to zero. If both functions are zero, the displayed resultant is zero.

In all the computational modes, the B averager memory contents are scaled to the same SENSITIVITY setting as that used during the accumulation of the A averager memory contents. For example, suppose a spectrum were averaged with a SENSITIVITY setting of 10 volts rms and transferred to the B averager memory, followed by another average with a SENSITIVITY setting of 1V rms. Then the B averager contents will be multiplied by a factor of 10^2 prior to doing any computation.

3-5. SPECTRUM AVERAGE Controls

This group of switches and indicators provides the necessary control and monitoring function for the spectrum averager of the Model 444.

A. MODE -
SUM/DIFF/EXPON/PEAK

This group consists of four interlocked pushbutton switches. Each of the four settings determines a unique processing mode in the averager. NOTE: A significant increase in the averaging speed can be obtained by turning both the CURSOR switch and the rear panel ANNOTATION switch to the OFF position.

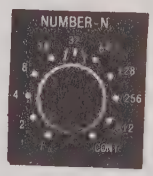
1. SUM - Successive 50 percent redundant spectra are added and stored in the averager memory on a cell-by-cell basis. A 50 percent redundant spectrum is defined as one obtained from a set of 1024 input time data points, 512 of which were used to derive the previously averaged spectrum. At higher analysis ranges (above 2 kHz) redundancy approaches zero. In the SUM averaging mode, averaging will continue until N spectra have been accumulated, where N is determined by the setting of the NUMBER-N switch.

2. DIFF - In this mode of averaging, successively averaged spectra are subtracted from whatever values have been stored in the averager memory prior to the start of this mode. If the result of the subtraction is negative, it is stored in the averager memory as a negative number, but the display will indicate a zero value. This mode is useful in minimizing the effect of background noise on a signal spectrum.

3. EXPON - This is a weighted summation mode, where recent spectra are more heavily weighted than older spectra. The weighting window is exponential with a constant equal to the setting of the NUMBER-N switch. For example, if the NUMBER-N switch is set to 128, then the 128th averaged spectrum before the currently averaged one is weighted by approximately .37 of its original value. Alternatively, the constant N indicates the number of averages required to bring the averaged value to 63 percent of its final value. The actual time constant corresponding to the N constant is determined by the time between non-redundant spectra.

4. PEAK - In this mode, each spectral value is examined and those spectral values that exceed values previously stored in corresponding locations are replaced. Thus, each location in the averager memory contains the largest value of the spectral point that occurred during the N spectra observed. The examination of each of the 400 new spectral values and the decision to store new peak values occurs at the same rate as SUM averaging.

B. NUMBER-N -
1/2/4/8/16/32/128/256/512/CONT



This switch selects the number of spectra averaged in the SUM, DIFF, or PEAK modes. The averaging process is automatically terminated and the output normalized when the pre-set number of spectra have been processed. When the CONT setting has been selected, the processing continues and the output is normalized as if 1024 were selected. In the EXPON mode, this switch sets the RC time constant. After the selected number of spectra have been averaged, the average value is 63 percent of its final value.

C. CONTROL -
START A/STOP A/CONT A/TRANS A→B

This group of momentary contact switches is used to control the Spectrum Averager.

1. START A - Depressing this button will erase the average A memory, except in DIFF mode where the averager memory is not erased, reset the NUMBER-N counter and start the averaging process.

2. STOP A - This button, when depressed, will stop the averaging process.

3. CONT A - If the averaging process has been stopped prior to reaching the preset NUMBER-N setting, then depressing the CONT A button will start the averager from the point at which it has been stopped and continue until it reaches the NUMBER-N control setting.

If the averager has accumulated the preset NUMBER-N of spectra, then depressing the CONT A button will cause the averager counter to be reset to zero (without erasing the averager A memory) and the averaging process will take another set of N spectra.

4. TRANSFER A→B - This button when depressed will transfer the current contents of averager memory A into memory B. The contents of memory A will not be altered by this operation. This is the only way in which the contents of memory B can be modified.

D. IN PROCESS

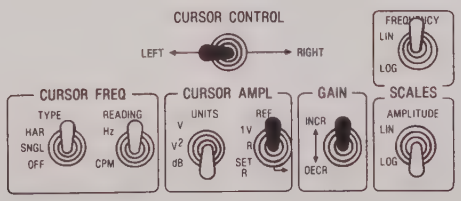
This LED indicator warns that an averaging cycle is in process. During the averaging cycle, this indicator flashes (the rate of flashing is not related to the averaging rate). However, there are exceptions in the following settings:

NUMBER-N/CONT - In this position, in all averaging modes, the IN PROCESS LED will continue to flash, even after the first 1024 spectra have been analyzed. Depressing the STOP pushbutton will stop averaging in this position.

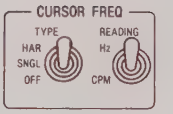
EXPON - After reaching the N constant selected by the NUMBER-N switch (except in the NUMBER-N/CONT position), the IN PROCESS indicator will remain illuminated, and averaging continues until the STOP pushbutton is depressed.

This indicator is normally off prior to initiating an averaging process and after completing the cycle.

3-6. The Display Controls



A. CURSOR FREQ - TYPE/READING



1. READING - Hz/CPM - This switch is used to obtain a cursor frequency readout in either Hz (Hertz) or CPM (cycles per minute), the latter being equal to 60 times the value in Hz. This control will function only when the cursor type switch is in either the SINGL or HAR position. The annotation field used to indicate the setting of the FREQUENCY RANGE switch will always read in Hz regardless of the setting of the READING-Hz/CPM switch.

2. TYPE - HAR/SINGL/OFF - This three position switch controls the display of a vertical cursor line on the CRT and the assocaited readout of amplitude and frequency.

OFF - In this position, the vertical cursor line, as well as the displayed values of amplitude and frequency, are turned off. (Except in the "AT CURSOR" or "PLOT" mode, see section 3-8, when the cursor line is on but the displayed values are off.)

SINGLE - In this position, a vertical line is generated from the top of the graticule to the bottom of the graticule at a frequency determined by the CURSOR CONTROL. The intersection of this cursor with the spectrum display will be intensified, unless the spectrum display is at a limiting value (i.e., full scale or zero) in which case there will be no intensification. (In "AT CURSOR" or "PLOT" modes the dot is always presented.) The amplitude of the intensified point of the spectrum display will be displayed in the annotation. The value displayed will be determined by the selection of the CURSOR AMPLITUDE and AMPLITUDE SCALE switches.

The horizontal coordinate of the cursor will be read out in Hz, CPM, or percent full scale according to the setting of the READING and FREQ/ORDERS switches.

HAR - In this position, the cursor is generated as above; in addition, at frequency addresses that are multiples of the cursor frequency address, the displayed spectrum point will be intensified. At the second harmonic address, two points (harmonic address plus address immediately following) are intensified. At the third harmonic address, three points

are intensified; at the fourth harmonic address, four points are intensified; for the fifth and higher harmonic addresses, five points are intensified. The increasing number of addresses intensified are required to identify harmonics of a signal frequency, since any slight offset of the fundamental from the center of the frequency analysis cell will result in a shift of a number of cells at higher harmonics. Note that in the "PLOT" mode no harmonic dots are displayed.

B. CURSOR CONTROL - LEFT/RIGHT

This is a center off momentary LEFT/RIGHT type switch. The LEFT position controls cursor motion to the left; the RIGHT position controls cursor motion to the right. The cursor will "single step" when the switch is activated in the RIGHT or LEFT positions for less than approximately two seconds. If held in either position for longer than two seconds, the cursor will slew at a rate of approximately 16 seconds per display span. This control is inoperative if in the "PLOT" mode.

C. CURSOR AMPL and GAIN

1. UNITS - This switch selects the units in which the CURSOR AMPLITUDE data is displayed. Units selectable are volts, V, volts squared, V^2 (power), and dB relative to the reference level selected by the REF switch. This control is functional only if the cursor is on.

2. REF - The reference levels for the UNITS switch are selected by the REF switch. This is a three position toggle switch where the lower SET R position is a momentary contact. Note that this switch will only function when the cursor is on. A fixed reference of 1V (equivalent to a 1V rms sinusoidal input) and a variable reference are available. When a 1V reference is selected, the cursor reads equivalent input signal levels in volts, $volts^2$, or dBV (dB with respect to 1V).

The variable reference level may be set in either of two ways:

a. To set the reference to a particular level on a spectrum display use the CURSOR CONTROL to move the

intensified dot of the cursor to the desired reference point on the spectrum. Depress the REF switch momentarily into the SET R position. The cursor readout is now relative to the level of the spectrum at the cursor location. If the UNITS switch is in the V position, then the cursor readout will be in units of R, if in the V^2 position, the readout will be in units of R^2, and if in the dB position the readout will be in dB relative to the SET position. For example, if the reference level were set on a spectral line whose absolute value was 0.5 volts, the readings for the three unit switch settings would be 1.00R, 1.00R^2, and 0 dBR. If the cursor were moved to read another spectral peak of double the amplitude, the three readings possible would be 2.00R, 4.00R^2, and 6 dBR. The original value of the set reference level is also displayed as 0.5V/R.

b. To set a reference to an arbitrary reference level depress and hold the REF switch in the SET R position. Observe the reference level field in the annotation (recognizable by its units, V/R). Note that the reference readout field of the display will change to the value of the spectrum at the cursor location. The GAIN control is used to change the reference level. Placing the GAIN control in the INCR position will cause the reference level to decrease. Similarly, holding the GAIN control in the DECR position will cause the reference level to increase. The range of possible reference values is from 1.00×10^{-9} to $999. \times 10^{-9}$. In order to enable the operator to cover this range quickly the GAIN control is a dual rate control. Holding the control in either position will cause the reference level to change at a relatively slow rate for the first one hundred counts; after this the reference level will change quite rapidly in order to cover a wide range of values quickly. After reaching the desired reference level simply release the GAIN control and REF switch and allow them to return to their neutral positions. Note that once the REF switch is released the reference level is fixed. If the REF switch is placed in the SET R position again, the existing reference level will change to the preset cursor amplitude level. All cursor levels will now be relative to the reference level R as described previously.

3. GAIN - This control is used in conjunction with the REF switch to set an arbitrary reference level as described above. It may also be used to control display GAIN. Holding the GAIN control in the INCR position will cause the display GAIN to increase in 10 dB steps for a LOG AMPLITUDE scale, and by factors of two for a LINEAR AMPLITUDE scale to a maximum of 50 dB or 512. It will take approximately one second for each

change in GAIN to be observed. In a like manner, holding the control in the DECR position will cause an attenuation of the display to a maximum of -50 dB or 1/512 depending on the AMPLITUDE SCALE selected. Refer to Section V for further details on the use of these controls. Display GAIN is annotated on the CRT display. Refer to paragraph 3-12 for details.

D. SCALES -
FREQUENCY/LIN/LOG
AMPLITUDE/LIN/LOG

1. FREQUENCY - The selection of a linear or logarithmic frequency axis is made using this switch.

In the LIN position, the horizontal axis represents equal spacings of 400 readout addresses. In the LOG position, the horizontal axis is scaled so that equal increments along this axis represent equal address ratios (e.g., the spacing between the 5th and 10th address will be the same as the spacing between the 10th and 20th address, as well as between the 200th and 400th address). When viewing TIME data, the horizontal axis will always be linear.

2. AMPLITUDE - This switch is active when viewing any output except TIME. (Only linear vertical scale is permitted when viewing TIME.)

In the LIN position for single displays, the graticule is divided into ten equal divisions with zero linear amplitude coinciding with the bottom graticule line, a full scale linear amplitude coinciding with the top graticule. In the dual display modes (i.e., INST/A, A/B, etc.), the vertical scale consists of two scales of ten equal spaces stacked one above the other. The center line (10th division) is the 0 level for the upper display and the full scale level for the lower display.

The linear amplitude scale has basic units of volts and represents the square root of the power spectrum. When using the LIN amplitude scale in conjunction with the GAIN control, gains of 1, 2, 4, 8, 16, 32, 64, 128, 256 and 512 are provided as well as attenuations of 1, 1/2, 1/4, 1/8, 1/16, 1/64, 1/128, 1/256, 1/512.

In the LOG position, the vertical scale is divided into six divisions, each division representing 10 dB, or two displays each with six divisions. The definition of 10 dB is a voltage ratio of 3.16:1, or a power ratio of 10:1. The six divisions, therefore, provide a viewing range of 60 dB, or 1000:1 voltage ratio, or one million-to-one power ratio. When the AMPLITUDE SCALE switch is in the LOG position, the GAIN control can be used to provide offsets of -50 to +50 dB in 10 dB steps. The LOG display will always extend over a 60 dB range but the maximum (full scale) point of the range may be offset by the GAIN control setting, as annotated to the left of the displayed graticule above the dB indication. The LOG AMPLITUDE SCALE setting is inoperative in the VIEW TIME switch setting. When viewing time data, the vertical axis will always be linear. For example: The GAIN control setting is at -10 dB. The top graticule line now represents +10 dB relative to the full scale setting of the SENSITIVITY control. Cursor readings are not affected by the AMPLITUDE SCALE or GAIN control settings.

3-7. RESOLUTION

This series of interlocked pushbutton switches is used to select the desired frequency resolution of the displayed spectrum.

A. 400 LINE - This position is used to select narrowband spectrum. The frequency resolution is 1/400 of the frequency range.

B. 1/3 OCT - (Optional) In this position a spectrum with 1/3 octave resolution is synthesized from the narrowband spectrum. Center frequencies, bandwidths and effective filter rolloffs meet ANSI Class III standards. When 1/3 octave resolution is selected, the frequency range is forced to the nearest 1/3 octave compatible range. The following table summarizes the 1/3 octave compatible frequency ranges and the characteristics of the 1/3 octave filters synthesized in each range:

1/3 octave:

Range Setting	Center Freq. Range (Hz)	(ANSI Std. 1/3 oct. band numbers)	Approx. Processing Time (sec)
5K	6.3 - 5,000	(Band 8 - 37)	2.4
10K	12.5 - 10,000	(Band 11 - 40)	1.2
20K	25 - 20,000	(Band 14 - 43)	.8
50K	50 - 40,000	(Band 17 - 46)	.8

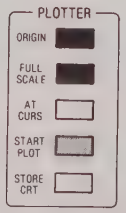
C. 1/1 OCT - (Optional) In this position a 1/1 octave spectrum is synthesized from the 1/3 octave spectrum. 1/1 octave filters meet ANSI Class II standards for all the filter characteristics described previously. As in the 1/3 octave resolution mode, selection of 1/1 octave mode will force the frequency range to the nearest 1/1 octave compatible range. 1/1 octave compatible frequency ranges are summarized below:

1/1 octave:

Range Setting	Center Freq. Range (Hz)	(ANSI Std. 1/1 oct. band numbers)	Approx. Processing Time (sec)
5K	8.0 - 4,000	(Band 9 - 36)	2.4
10K	16.0 - 8,000	(Band 12 - 39)	1.2
20K	31.5 - 16,000	(Band 15 - 42)	.8
50K	63 - 31,500	(Band 18 - 45)	.8

In either 1/3 octave or 1/1 octave modes, selection of TIME DISPLAY mode will result in an error message, "1/3 OCT" or "1/1 OCT" on the display CRT.

3-8. PLOTTER



This group of pushbutton switches controls the output on the rear panel PLOTTER outputs.

A. ORIGIN - When this switch is depressed, the X and Y plotter outputs are forced to the origin of the display. Pen lift contacts will be in the open condition (pen up).

The CRT display will remain unchanged except for the appearance of an intensified dot at the spectrum origin point (lower left hand corner of the graticule).

B. FULL SCALE - Depressing this pushbutton will result in the X and Y plotter outputs being forced to the full scale-full scale (upper right corner) point of the display. Pen-lift contacts will be open (pen up). An intensified dot will appear at the equivalent point on the CRT display.

C. AT CURS - When this switch is depressed the X and Y plotter outputs will read the current spectrum value at the display cursor location. The pen-lift contacts will be open (pen up). Even if the cursor is off the cursor line will be displayed.

D. START PLOT - When this pushbutton is depressed, the following sequence of events will occur.

1. The cursor which will be displayed in this mode, even if the cursor switch is off, will move to the extreme left hand graticule location on the CRT display, and pause.

2. Pen will drop.

3. The cursor will begin moving to the right, and the X and Y plotter outputs will track the spectrum or time value at the cursor location.

4. When the cursor reaches the right hand graticule limit, the pen-lift contacts will open (pen up) and the cursor will stop.

No further cursor control will be possible until the unit is taken out of the plotter mode by depressing the AT CURS, ORIGIN or FULL SCALE button.

E. STORE CRT - This position provides a single slow readout of the entire display to an external device as selected by the STORE MODE slide switch on the rear panel.

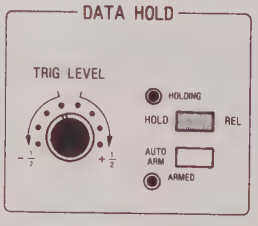
Upon completion of a single sweep, the display will automatically return to normal CRT display until the STORE CRT pushbutton is depressed again.

3-9. I.D. NUMBER

This digital switch is used to enter a four digit identification number in the lower left hand corner of the CRT display annotation. This I.D. number is easily recognized in the annotation by the number sign (#) which follows the four digit number.

Model 444-263, equipped with the optional FREQUENCY EXPANSION unit, uses the ORIGIN FREQUENCY switch to enter the I.D. number when the I.D. # control is in the ON position (FREQUENCY EXPANSION is OFF).

3-10. DATA HOLD



A. DATA HOLD

1. HOLD/REL - This momentary pushbutton switch provides alternate action to inhibit or allow collection of input data samples in the input buffer memory. There are no sample delays or threshold levels involved in the HOLD/REL operation, as with the AUTO ARM. Consequently, if the 444 is in the ARMED state and the HOLD/REL button is pressed, the system will go into HOLD immediately, and the previous 1024 samples are "frozen" in the input buffer memory. Pressing the HOLD/REL button a second time places the system in its released mode immediately.

2. HOLDING - This indicator is on whenever the system has been placed in a HOLD state due to transient capture or manual HOLD action.

3. AUTO ARM - This momentary pushbutton switch arms the threshold detection circuits to recognize the point

at which the input signal crossed the trigger level setting. When this point is detected, 896 additional samples are collected. Further collection of data samples is halted at this point. The threshold point is therefore represented by the 128th sample stored in the input buffer memory, which always holds the most recent 1024 samples collected.

4. ARMED - This indicator is on from the time that the AUTO ARM is activated until the TRIG LEVEL is exceeded, or until the HOLD/REL momentary action button is pressed.

B. TRIG LEVEL

This is an eight position switch used to control the threshold level of an input signal to be detected when capturing a transient. This switch is effective only when the AUTO ARM button is pressed. The maximum counter-clockwise position is set for -1/2; i.e., when the signal threshold is equal to or less than (algebraically) -1/2 full scale, the trigger level will have been exceeded. The next three positions are -1/4, -1/8, and -1/16, respectively. The following four positions are +1/16, +1/8, +1/4, and +1/2.

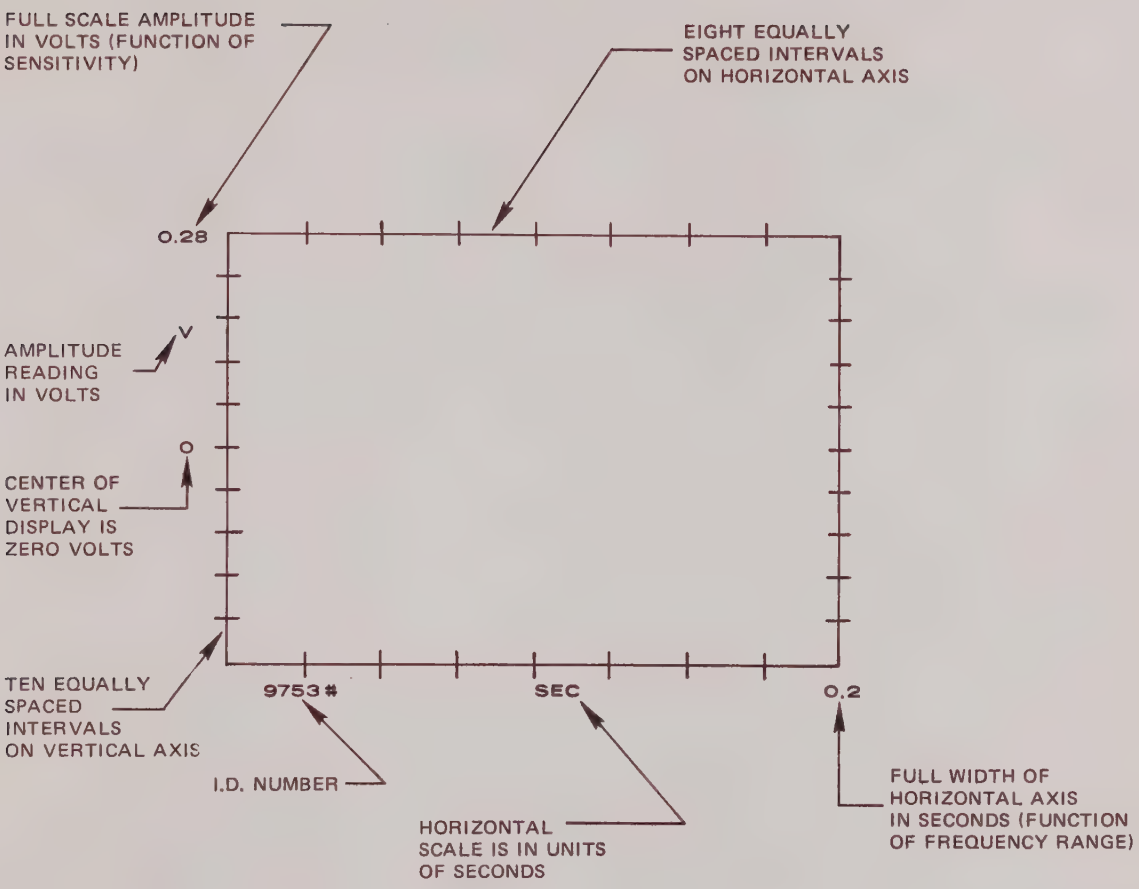
3-11. POWER

This control is used to turn the unit ON and OFF. The LED indicator will be illuminated when the unit is in the ON mode.

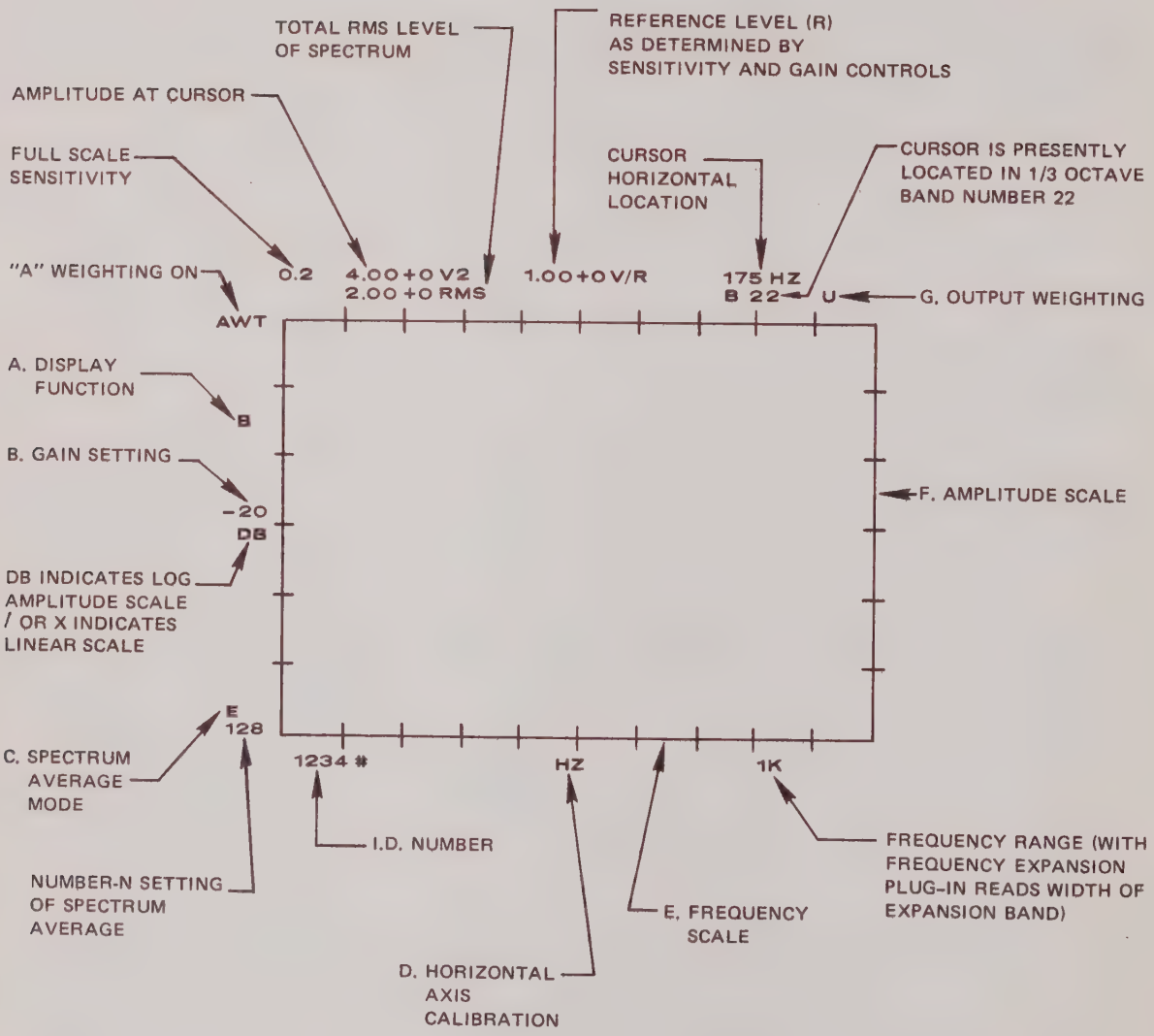
3-12. The CATHODE RAY TUBE (CRT) - The Display

The CRT display consists of an electronically generated graticule, a series of annotation fields which describe the control settings and the 444 output display. The following typical displays are used to describe the location and function of each annotation field. A series of tables follow the illustrations which describe each of the listings within the fields which have more than one possible indication. Letters appearing on the illustrations refer to the appropriate entry in the tables.

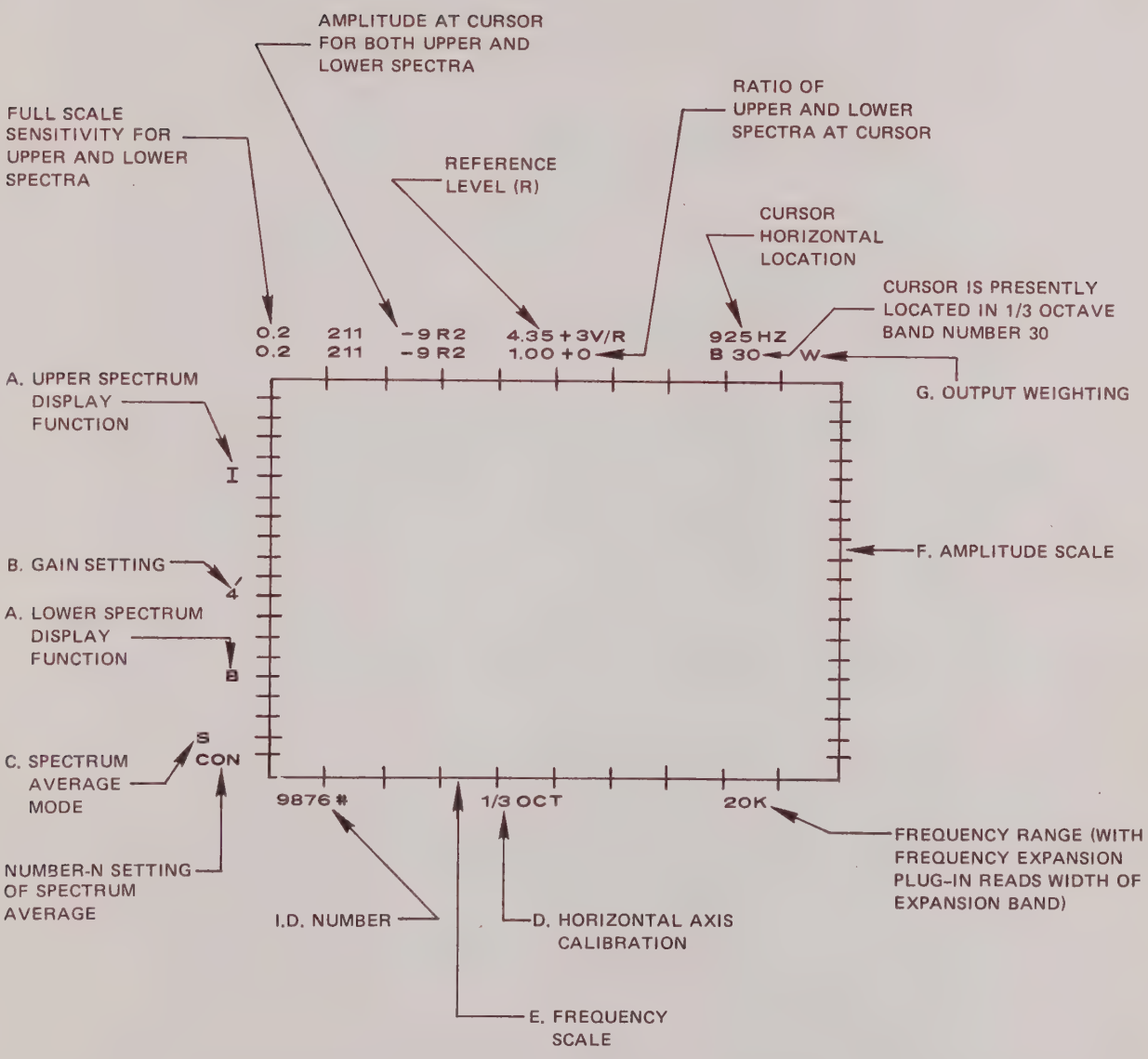
TIME DISPLAY


FULL SCALE AMPLITUDE IN VOLTS (FUNCTION OF SENSITIVITY)
EIGHT EQUALLY SPACED INTERVALS ON HORIZONTAL AXIS
0.28
AMPLITUDE READING IN VOLTS
V
0
CENTER OF VERTICAL DISPLAY IS ZERO VOLTS
TEN EQUALLY SPACED INTERVALS ON VERTICAL AXIS
9753#
I.D. NUMBER
SEC
HORIZONTAL SCALE IS IN UNITS OF SECONDS
0.2
FULL WIDTH OF HORIZONTAL AXIS IN SECONDS (FUNCTION OF FREQUENCY RANGE)

SINGLE SPECTRUM DISPLAY



DUAL SPECTRUM DISPLAY



A. DISPLAY FUNCTION

Display Mnemonic	Display Mode
V (volts)	TIME
I	INSTaneous Spectrum
A	Averager A Memory
B	Averager B Memory
A + B	A + B
A - B	A - B
A/B	A/B
B/A	B/A

B. GAIN

Log Amplitude Scale - -50 to +50 dB (in 10 dB increments) indicates amplitude of upper horizontal graticule line relative to SENSITIVITY control setting.

Lin Amplitude Scale - x512 to /512 (in powers of two) indicates factor by which full scale display amplitude has been multiplied or divided.

C. SPECTRUM AVERAGE MODE

S - SUM
D - DIFFerence
E - EXPONential
P - PEAK

D. HORIZONTAL AXIS CALIBRATION

(Hz) - frequency in Hertz
1/3 OCT - 1/3 OCTave RESOLUTION - Three 1/3 octave filters per division
1/1 OCT - 1/1 OCTave RESOLUTION - One octave filter per per horizontal division

E. FREQUENCY SCALE

Log Frequency - 3 decade divisions full scale, 0.1 full scale, 0.01 full scale

Lin Frequency - 10 equal divisions

F. AMPLITUDE SCALE

Log Amplitude - Six (6) equal divisions (10 dB/div) per display

Lin Amplitude - Ten (10) equal divisions per display

G. OUTPUT WEIGHTING

W - Hanning (continuous) Weighting
U - Uniform (transient) Weighting

3-13. STORE MODE (Rear Panel)

This switch is used to select the appropriate store CRT display for specific external recording devices.

A. CRT - In this position the store CRT mode will output data to a Tektronix Model 613 Storage Display unit via the rear panel external display X and Y and the Model 613 Z axis BNC connector.

B. PLOT - In this position the 444 will output data to a Tektronix 4000 Series terminal or 4662 digital X-Y plotter via the connector J103.

C. AUX - In this position the 444 will input or output data from the external peripheral units summarized in the following table. In each case the appropriate setting of the hexadecimally coded switches (located on the ENCODER board at location E32) necessary to format data properly, is also given.

3-14. External Peripheral Selection

PERIPHERAL	SWITCH E32 SETTING		
	Fast Peak Averager*	Normal Peak Averager	Rear Panel Interface Connector
1. 144 Digital Cartridge Recorder	0	8	J101 and J102
2. Start Paper Tape Reader	1	9	J101 and J102
3. RS232 Output			
a. Sense and real/ imaginary dump	2	A	J103
b. Sense and spectrum or time	4	C	J103
c. Sense, real/ imaginary dump and spectrum or time	6	E	J103
4. Paper Tape Punch			
a. Sense and real/ imaginary dump	3	B	J101 and J102
b. Sense and spectrum or time	5	D	J101 and J102
c. Sense, real/ imaginary dump and spectrum or time	7	F	J101 and J102

*Note: In fast peak averager mode, averager is updated at the processing rate rather than the 50 percent redundancy rate normally used.

3-15. WEIGHTING WINDOW (Rear Panel)

A. FLAT - This position of the switch leaves the input data block unweighted (or uniformly weighted) and provides a slow rolloff of the effect of any single point in the frequency domain due to the finite length of input signal processed.

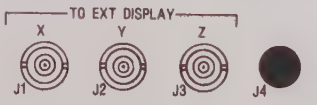
B. HANN - In the HANN position of this switch, the input data block is weighted, or multiplied, by the function $\sin^2 \pi n/1024$, where "n" represents the position of the sample in the 1024 data block. This weighting function is also referred to as Hanning weighting and provides for a sharper rolloff of the signal in the frequency domain due to the finite length of the input signal, than that provided by uniform weighting.

C. AUTO - In this position the flat weighting function is automatically selected whenever the AUTO ARM pushbutton is depressed. This automatically prepares the unit for analysis of transient data. When the HOLD function is cleared, the weighting is returned to the Hanning weighting.

3-16. RESET (Rear Panel)

This pushbutton switch is a master reset for the 444 processor. Depressing this button will reinitialize the system program and clear the A averager memory.

3-17. TO EXT DISPLAY
X, Y, Z BNC Outputs



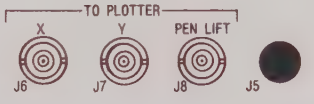
The outputs at these BNC connectors match the corresponding signals to the internal CRT and have the following nominal voltage levels:

A. J1 - X - Horizontal Output. 0 to +1 volt, analog. +1 volt corresponds to right of screen.

B. J2 - Y - Vertical Output. 0 to +1 volt, analog. +1 volt corresponds to top of screen.

C. J3 - Z - Z-axis (intensity axis) Output. 0 to -2 volts, digital. 0 volts should turn beam on; (-2 volts should turn beam off). (Internal jumpers allow other polarities and levels.)

3-18. TO PLOTTER
X, Y, PEN LIFT
BNC Output



These connectors are used in the plotting mode and provide the X and Y analog output signals to the plotter, as well as a Pen Lift signal used to activate the pen when plotting. The signals are defined as follows:

A. J6 - X - Horizontal Output. This signal goes from 0 to +3.2 volts while plotting.

B. J7 - Y - Vertical Output. This signal goes from 0 to +3.2 volts.

C. J8 - PEN LIFT. This is a relay contact closure during plotting. Contacts are open at all other times.

When the AT CURS button of the PLOTTER mode switch group is depressed (front panel), the voltages at the X and Y plotter outputs reflect the current cursor locations. PEN LIFT - up.

3-19. AVG TRG OUT/ARM TRG IN
613 Z AXIS BNC Connectors

A. J9 - AVG TRIG OUT - This is a digital signal indicating that the 444 input buffer memory has been read out and is available for loading new data. The signal is normally in the high state (+2.5 to +5.0 volts) and goes low (0 to +.7 volts) for 1/2 microsecond when the input buffer readout is complete.

B. J10 - ARM TRG IN - A digital input pulse at this connector will arm the circuits in the -10 Plug-In unit to accept an input signal above the threshold level established by the TRIG LEVEL front panel control which will place the 444 into HOLD after the following 896 samples. The pulse is a normally high level and goes low for at least 1 microsecond. It is the low to high (trailing edge) transition that will cause the arm operation. The pulse duplicates the effect of the AUTO ARM switch.

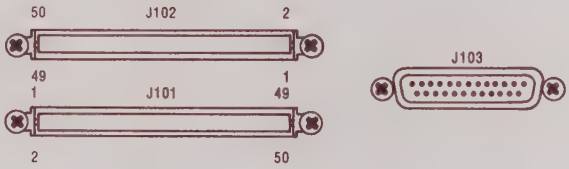
C. J11 - 613 Z AXIS - This is a logic output signal that is active during the readout of the spectrum into the 613 storage oscilloscope. The level is normally low and will go high during

the 613 readout whenever a display point is to be written onto the 613 cathode ray tube.

3-20. 66-2A Gate and 66-2A Trigger

66-2A Gate (X AVG SWEEP)	High level during the spectrum or time display for use with 66-2A.
66-2A Trigger (X STB 2)	Pulse used to transfer data to 66-2A.

3-21. J101, J102, and J103 Connectors



A. J101 - 50 pin connector with pin assignments as follows:

Pin	Mnemonic	Explanation
1	XDS0	External, bus multiplexer select code, bit 0
2	XDS1	External, bus multiplexer select code, bit 1
3	XDS2	External, bus multiplexer select code, bit 2
4	XDS3	External, bus multiplexer select code, bit 3
5	XDSEL	Forces bus multiplexer control to external code (XDS0 through XDS3)
6-25	XD0-XD19	External data input bus, bits 0 through 19
26-45	DX0-DX19	External data output bus, bits 0 through 19
46	X IN DATA WRITE PULSE	.5 μsec high to low pulse whenever data is written into the input buffer memory
47	X INT AD EN	Controls source of data into input buffer memory: high = internal A/D converter data low = external data on DX bus

Pin	Mnemonic	Explanation
48	Ground	
49	$\overline{\text{DX READ}}$	Negative 2 μsec pulse signifying that the 444 is outputting data on the DX bus
50	D BUS EN	Normally high level enables DX0 through DX15

B. J102 - 50 pin connector with pin assignments as follows:

Pin	Mnemonic	Explanation
1	$\overline{\text{X 2 MS CLK}}$	High to low .5 μsec pulse every 2 msec
2	$\overline{\text{X PC LD INH}}$	Low level inhibits loading of program counter. Normally high to enable loading
3-7	$\overline{\text{X FLG 0}}$ - $\overline{\text{X FLG 4}}$	Five flags individually activated by low levels to signal 440 for appropriate action
8	$\overline{\text{X HALT}}$	Forces system to repeat current logic step as long as signal is held low
9	$\overline{\text{X PADV EN}}$	When low inhibits all 440 logic steps and enables external stepping clock $\overline{\text{X PADV}}$
10	$\overline{\text{X PADV}}$	Enabled by $\overline{\text{X PADV EN}}$. Low to high transition causes the system to advance one logic step
11	LOAD PCX	High level indicates that Program Counter is being loaded
12	Z AXIS ON	High when Z AXIS ON, low when Z AXIS OFF
13	X AVG SWEEP	High level during spectrum or time data display
14	$\overline{\text{X LD PC}}$	Low input to load Program Counter
15	X LD PC SYNC	Synchronized version of Signal 14
16-25	PC0X - PC9X	Buffered Program Counter outputs 0 through 9
26	$\overline{\text{X STOP}}$	Pulse, high to low to high, input, parallels front panel STOP button activation
27	$\overline{\text{X CONT}}$	Pulse, high to low to high, input, parallels front panel CONT button activation

Pin	Mnemonic	Explanation
28	$\overline{\text{X RESET}}$	Pulse, high to low to high, input, parallels front panel RESET button activation
29	$\overline{\text{X START}}$	Pulse, high to low to high, input, parallels front panel START button activation
30	$\overline{\text{X HOLD/REL}}$	Pulse, high to low to high, input, parallels front panel HOLD/REL button activation
31	$\overline{\text{X ARM}}$	Pulse, high to low to high, input, parallels front panel ARM button activation
32	$\overline{\text{X BLK SYNC}}$	Pulse, high to low to high, input, minimum 2 μsec low to clear Buffer Full level and input buffer sample counter
33	$\overline{\text{X BUFF FULL}}$	Normally high output. Goes low whenever buffer is full. Returns to high level when $\overline{\text{X BLK SYNC}}$ is issued
34	$\overline{\text{X AD READY}}$	Pulse, high to low to high, input; causes XD0 through XD10 to be written into input buffer whenever X INT AD EN is low
35	PC 10X	Buffered Program Counter, bit 10
36	$\overline{\text{STOP ON FULL}}$	Low input causes input buffer to stop when full
37	X STB 0	Unassigned
38	X STB 1	Unassigned
39	X STB 2	Pulse used to transfer data to 66-2A
40	X PADV EN SYNC	Same as Signal 9 except inverted and synchronized to internal clock
41	X STB 3	Complement of AVG TRIG OUT BNC
42	PCBX	Program counter M.S.B.
43	$\overline{\text{X RTC INH}}$	Display inhibit/plotter stall
44	GRD	Ground return
45	$\overline{\text{SMOOTHING INH}}$	Low disables display smoothing
46	$\overline{\text{XCTRL}}$	High to low transition activates peripheral devices on depressing STORE CRT button
47	$\overline{\text{AVG IN PROC}}$	Low indicates averager processing

Pin	Mnemonic	Explanation
48	$\overline{\text{REM LED}}$	High to low transition from peripheral device to 444 to acknowledge acceptance of data and reset $\overline{\text{XCTRL}}$
49	$\overline{\text{X STOR CRT}}$	Remote store CRT input pulse high to low parallels front panel STORE CRT button
50	$\overline{\text{XA}\rightarrow\text{B}}$	Remote transfer A→B, pulse high to low parallels front panel transfer A→B

C. J103 - RS232C Interface Connector

Pin	Mnemonic	Explanation
1	FRAME GND	Frame (shield) ground
2	TRANSMIT DATA	Serial data into 444
3	RECEIVE DATA	Serial data from 444
4	REQUEST TO SEND	Signal from external device to 444 requesting access
5	CLEAR TO SEND	Signal from 444 to external device
6	DATA SET READY	This line is asserted when data is transmitted from the 444
7	SIGNAL GND	Signal ground return
8	CARRIER DETECT	Indicates 444 is in a POWER ON condition. Asserted when POWER ON.
9-25	NO CONNECTION	

SECTION IV

CHECKOUT PROCEDURE USING INTERNAL TEST SIGNAL

4-1. Scope of This Section

This section of the instruction manual contains a step by step procedure for checking the 444 using the internal TEST signal. Verification of the required result is seen on the display.

4-2. Initial Setting

Set the front and rear panel controls as indicated in Table 4-1.

4-3. Graticule Annotation Check

This section of the checkout procedure verifies correct operation of the annotation fields by echoing control settings on the CRT display.

A. Verify that the display on the CRT is the same as that shown in Figure 4-1. Change the setting on the I.D. Number digital switch (origin frequency in units equipped with Option -26). Verify that the I.D. number in the lower left hand corner of the display matches the I.D. number on the front panel. Note that in units equipped with the Option -26 Frequency Expansion the least significant digit is locked at zero and is not shown in the I.D. number field. Change each decade of the I.D. number digital switch through its entire range and verify that the I.D. number field of the display matches the switch setting in every case.

4-4. SENSITIVITY Control and AMPLITUDE Indicator Check

Note the full scale voltage amplitude field in the upper left hand corner of the display. This field should read 0.14V. Place the SENSITIVITY control in the 200 MV position. Note that the full scale voltage amplitude field now reads 0.28V and that the time waveform displayed on the screen has decreased to 1/2 amplitude. The -6 dB AMPLITUDE indicator may flicker or be extinguished at this point.

TABLE 4-1

CONTROL SETTINGS

CONTROL	SETTING
POWER	ON
INPUT AMPLITUDE	
TEST/AC/DC	TEST
AMPLITUDE Indicators	All ON
OVERLOAD Indicator	OFF
SENSITIVITY	100 MV (-20dB)
A-WT	OFF
FREQUENCY RANGE	10,000 Hz
FREQ/ORDERS	FREQ
DATA HOLD	REL
HOLDING Indicator	OFF
TRIG LEVEL	+1/2
AUTO ARM	OFF
ARMED Indicator	OFF
FREQUENCY EXPANSION (Optional)	OFF/I.D.# ON
CURSOR CONTROL	
CURSOR FREQ	OFF
READING	Hz
UNITS	dB
REF	1V
FREQUENCY SCALE	LIN
AMPLITUDE SCALE	LOG
RESOLUTION	400 LINE
PLOTTER	ORIGIN
SPECTRUM AVERAGE	
NUMBER	1
MODE	SUM
DISPLAY	TIME
REAR PANEL	
WEIGHTING WINDOW	HANN
ANNOTATION	FULL
STORE MODE	CRT
I.D. NUMBER (Origin Frequency in units equipped with -26 Option)	0000

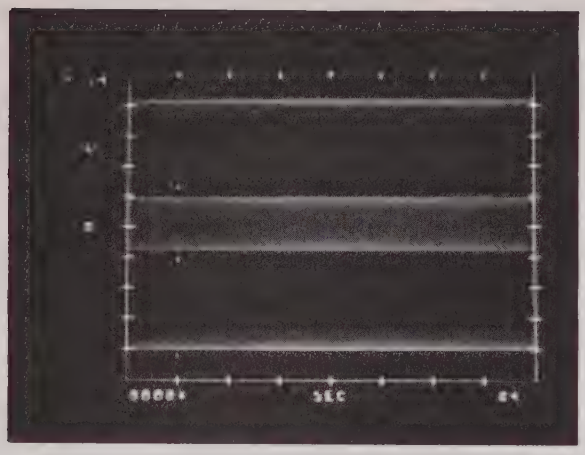


FIGURE 4-1

Rotate the SENSITIVITY control to the positions shown in Table 4-2 below. In each case verify that the indicated change in the display and amplitude indicators are correct.

TABLE 4-2

SENSITIVITY	Full Scale Amplitude Annotation Field	Amplitude Indicator
500 MV	0.70	-6 OFF -18 ON
1V (0dBV)	1.4	-18 OFF -24 ON
2V	2.8	-18 OFF -24 Maybe OFF or ON
5V	7.0	All Indicators OFF
10V	14.	All Indicators OFF

Return the SENSITIVITY control to the 100 MV (-20dBV) position.

4-5. FREQUENCY RANGE Check

Note the full scale time field in the lower right hand corner of the display. This field should read .04 SEC. Place

the FREQUENCY RANGE switch in each position given in Table 4-3 and verify the correct full scale time field annotation.

TABLE 4-3

FREQUENCY RANGE (In Hz)	Full Scale Time Field (In SEC)
100,000	.004
50,000	.008
20,000	.02
5,000	.08
2,000	.2
1,000	.4
500	.8
200	2
100	4
50	8
20	20
10	40
5	80
2	200
1	400

Return the FREQUENCY RANGE switch to the 10,000 Hz range.

4-6. CURSOR Check

Depress the DISPLAY INST pushbutton; the display should change. Verify that the graticule and annotation are the same as shown in Figure 4-2.

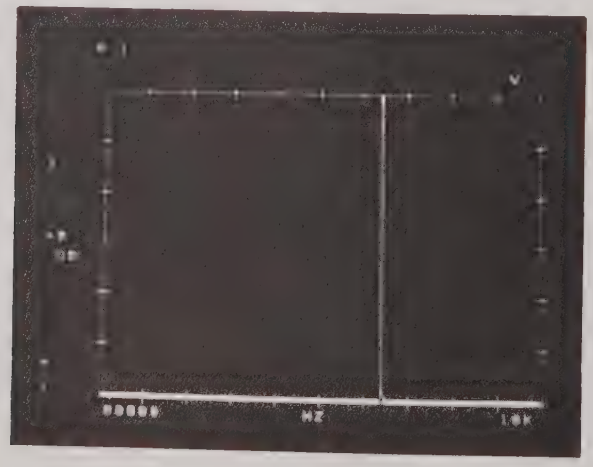


FIGURE 4-2

Place the CURSOR FREQ TYPE switch into the SNGL position. Note the appearance of a vertical cursor line and cursor annotation fields on the display. Verify that the cursor annotation fields are similar to those shown in Figure 4-3. The numerical values on the display may be different from those shown in Figure 4-3, but the same annotation fields must appear.

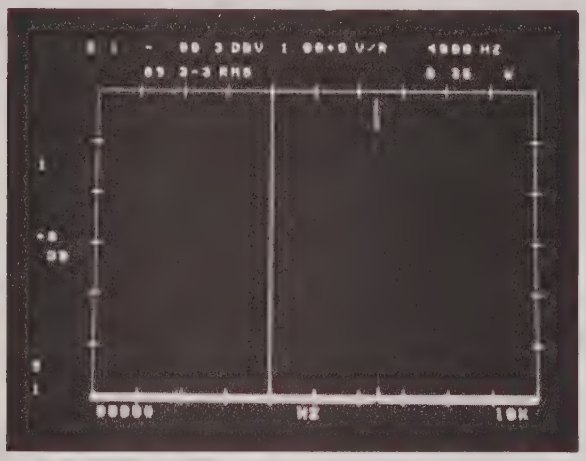


FIGURE 4-3

Momentarily push the CURSOR CONTROL lever switch to the right (do not hold the switch in this position). Notice that the cursor frequency readout field of the annotation (upper right hand corner of the display) increases by 25 Hz each time the CURSOR CONTROL is tapped to the right.

Momentarily push the CURSOR CONTROL switch to the left. Notice that the cursor frequency readout field decreases by 25 Hz each time the CURSOR CONTROL switch is activated. Note that the 25 Hz movement of the cursor frequency readout is a function of the FREQUENCY RANGE. Hold the CURSOR CONTROL switch to the right. The vertical cursor line will now move continuously to the right. The cursor frequency annotation field and the 1/3 octave band number field located immediately below it will also increase until the cursor line reaches the right hand edge of the display. When the cursor reaches the right hand edge of the graticule, it will "wrap around" and appear at the left hand edge of the display. At that time the cursor frequency annotation field and 1/3 octave band number will be reset. (For the 10,000 Hz FREQUENCY RANGE the cursor frequency annotation will read 25 Hz and the 1/3 octave band number will read 14 at the first cursor location to the right of the left hand graticule limit).

Hold the CURSOR CONTROL lever switch to the left. Verify that the vertical cursor line on the display moves continuously to the left and that the cursor frequency readout and 1/3 octave band number annotation fields decrease. When the cursor reaches the left hand limit of the display it will "wrap around" and appear at the right hand limit. Notice, also, that the cursor frequency and 1/3 octave band annotation fields change from their minimum to maximum valves when the cursor "wrap around" occurs. Place the FREQ/ORDERS switch to the ORDERS position. Repeat the above test. Note that the cursor frequency readout is now in percent of full scale, where 100 percent corresponds to the right hand edge of the display. The minimum frequency readout increment is 0.25 percent (1/400 of full scale). Restore the FREQ/ORDERS switch to the FREQ position.

Using the CURSOR CONTROL switch, move the display cursor until it coincides with the spectral line at 64 percent of the frequency axis. Notice that as the cursor crosses the spectral line, a bright dot will appear to indicate the point of intersection between the display and the cursor line. Observe the cursor amplitude readout annotation field. This field on the top line of the display is easily recognized by the units DBV. This field should read -20 DBV $\pm$2. The total rms level readout field, located directly below the cursor amplitude readout field, should read 100 -3 RMS, $\pm$21 -3.

Place the CURSOR AMPL UNITS switch into the V position. The cursor amplitude readout field should read 100 -3V $\pm$21 -3.

Place the CURSOR AMPL UNITS switch into the V2 position. The cursor amplitude readout field should indicate 10 -3V2 $\pm$4.4 -3. Return the CURSOR AMPL UNITS switch to the dB position.

Use the CURSOR CONTROL to move the display cursor to the 1000 Hz position. The cursor should be coincident with the first "tic" mark.

Place the CURSOR FREQ READING switch into the CPM position. The cursor frequency readout field on the display (upper right hand corner) should change from 1000 Hz to 60,000 cpm. Return the CURSOR FREQ READING switch to the Hz position.

Place the CURSOR FREQ TYPE switch into the HAR position. Note the appearance of eight intensified areas on the display.

The beginning of each area is coincident with a frequency axis "tic" mark. Note that the width of the intensified areas increases from the second through the sixth tic marks and thereafter remains a fixed width.

4-7. Frequency and Amplitude Scale Check

Set the FREQUENCY SCALES to the LOG position. Note that the annotation below the frequency (horizontal) axis changes from Hz to LOG Hz. The number of "tic" marks on the frequency axis should change from 10 (for the LIN scale) to 2 (for the LOG scale). Note also that the intensified areas on the frequency axis are logarithmically compressed and occupy the area between the second tic mark and the right hand edge of the display graticule.

Return the FREQUENCY SCALES switch to the LIN position, and the CURSOR FREQ TYPE switch to OFF.

4-8. Display GAIN Check

Depress the GAIN switch to the DECR position. Hold the switch in that position until the display gain annotation field (located on the left hand edge of the display) reads -50 dB. The amplitude of the displayed test signal spectrum should decrease until it is approximately five graticule divisions below full scale.

Momentarily hold the GAIN switch in the INCR position until the display gain annotation field reads -40 dB. The amplitude of the test signal should be approximately four graticule divisions below full scale (i.e. the top of the graticule).

Continue increasing the display gain in 10 dB steps until zero dB is reached. In each case, the test signal spectrum should increase by one graticule division for each 10 dB of gain.

After zero dB display gain is reached, rotate the SENSITIVITY control to the 10V (+20 dB) position. The amplitude of the test signal spectrum should be approximately 4 $\pm$2 graticule divisions below full scale.

Continue increasing the display gain in 10 dB steps until +40 dB is reached. Each increase of 10 dB in display gain will

result in the spectrum of the test signal increasing by one graticule division. Note that as the display gain is increased above zero dB, the noise floor of the analyzer will become visible. At the +40 dB display gain setting, the noise floor should be centered between the third and fourth graticule divisions below full scale (≈75 dB).

Increase the display gain to +50 dB. Note that the spectrum of the test signal intersects the top graticule line. Rotate the SENSITIVITY control to 100 MV (-20dBV). Set the AMPLITUDE SCALES switch to the LIN position. Depress and hold the GAIN switch in the DECR position until a display gain of /512 is obtained as annotated to the right of the display graticule. The spectrum of the test signal should not be visible. Momentarily place the GAIN switch in the INCR position until a display gain of /256 is obtained. The test signal spectrum should be barely visible above the lower graticule line.

Continue increasing the display gain in binary steps until a gain of X1 is obtained. Each display gain step should double the height of the test signal spectrum.

Rotate the SENSITIVITY control to the 10V (+20dBV) position. The spectrum of the test signal should be barely visible above the lower graticule line. Continue to increase the display gain until a reading of X512 is obtained. The spectrum of the test signal will double in amplitude for each display gain step. Note that with display gain of 256 and above the test signal spectrum will intersect the upper graticule line. The noise baseline will also become evident above gain settings of X8. Return the AMPLITUDE SCALES switch to the LOG position and DECR display gain until 0 dB is obtained.

4-9. Cursor Reference Set Check

Set the CURSOR FREQ TYPE switch to the SNGL position. Rotate the SENSITIVITY control to the 100 MV (-20dBV) position. Use the CURSOR CONTROL to align the display cursor with the test signal spectrum at 6400 Hz. Set the CURSOR AMPL UNITS switch in the V position. Observe and record the cursor amplitude readout. Note also that the reference field in the display annotation reads 1.00+0V/R. Depress the CURSOR AMPL REF switch momentarily into the SET R position. Upon release it will remain in the R position. Observe that the reference field of

the display annotation is now identical with the recorded value of the cursor amplitude readout. The cursor amplitude readout should read 1.00+0R and the total rms level readout should read approximately 1.00+0 RMS.

Depress and hold the CURSOR AMPLITUDE REF switch in the SET R position. Simultaneously depress the GAIN switch into the INCR position. Observe that the reference level field of the display annotation is decreasing. The minimum range is 0.0+0 V/R. Without releasing the CURSOR AMPLITUDE REF switch hold the GAIN switch in the DECR position. Observe that the reference level annotation field is increasing. The maximum range is 999.+9 V/R. (Note that the annotation field may overflow to XXX+9.) During the time that the reference level is changing, the cursor amplitude and total RMS annotation fields will be changing in a direction opposite to the reference level. Release the CURSOR AMPL REF and GAIN switches.

4-10. DATA HOLD check

Rotate the INPUT AMPLITUDE SENSITIVITY control to the 200 MV position. Depress the AUTO ARM pushbutton. The ARMED indicator should be illuminated. Rotate the TRIG LEVEL control one position counter clockwise (+3/8). The ARMED indicator should be extinguished and the HOLD indicator should be illuminated.

Rotate the TRIG LEVEL control to the -1/2 position. Repeat the test above with the following exception; the TRIG LEVEL control should be rotated clockwise by one position (to -3/8). The result should be the same as above.

Clear the HOLD indicator by depressing the HOLD/REL pushbutton. Return the SENSITIVITY control to the 100 MV (-20dBV) position.

4-11. Average Mode and Display Check

Set the CURSOR FREQ TYPE switch to the OFF position. Depress the DISPLAY A pushbutton. Verify that the average mode annotation field (lower left hand corner of the display) reads S (for SUM MODE). Depress the SPECTRUM AVERAGE to DIFF MODE pushbutton. The average mode annotation field should read D. Similarly, the average mode annotation field should read E and P for the EXPONential and PEAK MODE respectively.

Depress the SUM MODE pushbutton again. Note the number N annotation field (located immediately below the averager mode annotation field) should read 1. Rotate the NUMBER-N control through its entire range. At each position, verify that the NUMBER-N switch and the display annotation field are identical. Restore the NUMBER-N control to the 1 position.

Depress the START A pushbutton. The IN PROCESS indicator should be momentarily illuminated. The spectrum of the test signal (a single spectral line at 6,400 Hz) should be evident.

Repeat the above test for NUMBER-N control settings of 2 through 512. In each case the resultant spectrum should be identical. The IN PROCESS indicator should flash until processing is completed. The length of time the IN PROCESS indicator flashes should double for each doubling of the NUMBER-N setting.

Rotate the NUMBER-N control to the CONT position. Depress START A, the IN PROCESS indicator should be illuminated. (In units with Serial Numbers 70-48-037 and higher, the indicator will flash.) Notice that the amplitude of the test spectrum will increase slowly. Depress the STOP A pushbutton. The IN PROCESS indicator will be extinguished and the test spectrum amplitude will remain stable. Depress the CONT A pushbutton. The IN PROCESS indicator should be illuminated again and averaging of the test spectrum will resume. Depress STOP A and rotate the NUMBER-N control to the 32 position.

4-12. Averaging Display Mode Check

Depress the START A pushbutton. Wait until the IN PROCESS indicator stops flashing. Verify the presence of the test signal spectrum at 6,400 Hz. Depress the DISPLAY B pushbutton. Ignore the display. Depress the TRANSFER A B pushbutton. The display should be identical with the test signal spectrum obtained above.

Depress the $\frac{\text{INST}}{\text{A}}$ pushbutton. The display should be similar to Figure 4-4. Rotate the SENSITIVITY control to the 10V (+20dBV) position. Observe that the upper spectrum display decreases in amplitude to approximately four divisions below full scale.

Depress the $\frac{\text{INST}}{\text{B}}$ pushbutton. The only change in the display should be the change from A to B on the display and

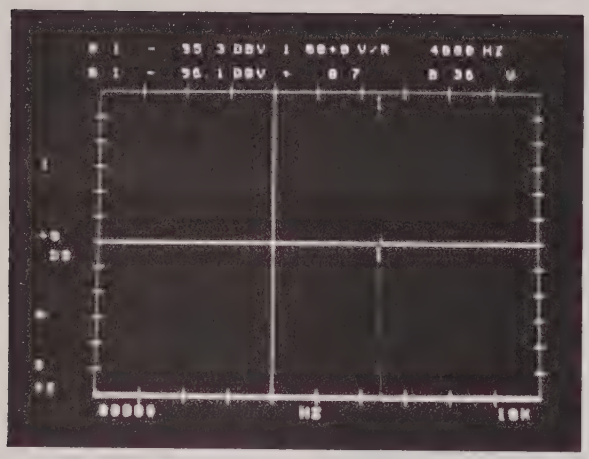


FIGURE 4-4

function annotation on the left hand edge of the display. Return the SENSITIVITY control to the 100 MV (-20dBV) position. Observe that the upper spectrum amplitude increases to nearly full scale.

Depress the $\frac{A}{B}$ pushbutton. The display should remain unchanged except for the displayed function annotation which should read A on the upper display and B on the lower.

Rotate the SENSITIVITY control to the 200 MV position. Depress the DISPLAY A pushbutton. Depress the START A and wait for processing to stop. Place the CURSOR FREQ TYPE switch into the SNGL position. Use the CURSOR CONTROL to line the vertical display cursor with the test signal spectrum at 6,400 Hz. Place the CURSOR AMPL UNITS switch in the dB position. Note the amplitude of the test signal spectrum on the cursor amplitude annotation field. Depress the TRANSFER A B pushbutton. Display the B averager memory by depressing DISPLAY B. Note that the cursor amplitude readout is the same as previously recorded. Depress the A+B pushbutton. Note that the cursor amplitude readout should increase by 3 dB (e.g., if -22 dB were originally recorded on average A, then A+B should read -19 dB).

Depress A-B, note that the test signal spectrum amplitude is attenuated. (Note that a spectral line of low amplitude

>30 dB below full scale) may be visible. This is normal. The cursor amplitude readout will be more than 30 dB below the reading obtained previously.

Depress the B-A, note a similar result. The cursor amplitude readout may be different from that obtained for A-B. A reading of -XXX indicates a zero condition. Rotate the SENSITIVITY control to the 100 MV (-20dBV) position. Depress START A and wait until processing is complete. Depress the TRANSFER A→B pushbutton. Rotate the SENSITIVITY control to the 200 MV position. Depress the START A pushbutton and wait for processing to stop. Depress the A/B pushbutton. Place the CURSOR AMPL UNITS switch to dB and the REF switch to 1V. Use the GAIN control switch to adjust the display gain to -20 dB. Use the CURSOR CONTROL to align the display cursor with the test signal spectral peak at 6,400 Hz. Note the cursor amplitude reading (it should be approx. 0 dBV). Note that the average amplitude of the remaining spectrum points is approximately 6 dB higher than the point measured above.

Depress the B/A pushbutton. Note that the 6,400 Hz spectrum point is now an average of 6 dB higher than the remaining spectrum points. Restore the display gain to 0 dB by using the GAIN control. Depress the DISPLAY A pushbutton.

4-13. Averager Mode Check

Depress the DIFF MODE pushbutton. Depress the START A pushbutton and observe the display. Notice that the test signal spectrum slowly decreases to near zero.

Depress the EXPON MODE pushbutton. Depress the START A pushbutton. Observe that the IN PROCESS light will flash for approximately 15 seconds and then remain illuminated continuously. Rotate the SENSITIVITY control to the 100 MV (-20dBV) position. Observe that the test signal spectrum slowly increases to approximately -20 dB as read on the cursor amplitude readout. Depress the STOP A pushbutton. The IN PROCESS indicator should be extinguished.

Depress the PEAK MODE pushbutton. Rotate the SENSITIVITY control to the 10V (+20dBV) position. Set the NUMBER-N control to the CONT position. Depress the START A pushbutton. Observe that the amplitude of the spectrum of the test signal is approximately four graticule divisions below full scale. Rotate the

SENSITIVITY control to the 1V (0dBV) position. Observe that the amplitude of the test signal spectrum increases by two graticule divisions. Set the SENSITIVITY control back to the 10V (+20dBV) position. Verify that the amplitude of the test signal spectrum does not change. Depress the STOP A and the SUM MODE pushbuttons. Rotate the NUMBER-N control to the 1 position. Depress the DISPLAY INST pushbutton.

4-14. Plotter Mode Check

Rotate the INPUT AMPLITUDE SENSITIVITY to the 100 MV (-20dBV) position. Depress the PLOTTER ORIGIN pushbutton. Note the appearance of an intensified dot located at the lower left-hand corner of the graticule. Depress the PLOTTER FULL SCALE pushbutton and note that the intensified dot is now located in the upper right-hand corner of the display graticule.

Place the CURSOR FREQ TYPE switch into the OFF position. Verify that the cursor is not visible on the display. Depress the PLOTTER AT CURSor pushbutton. The cursor should appear but no cursor annotation should be evident. Depress the PLOTTER START PLOT pushbutton. Note that the cursor will disappear momentarily and then reappear at the left-hand side of the graticule moving toward the right. Notice that as the cursor intersects the spectral line at 6400 Hz, the points of intersection will be intersected. The cursor will also pause momentarily as it crosses the test signal spectral line. Depress the PLOTTER AT CURSor pushbutton.

Depress the STORE CRT pushbutton. Note that each time this button is depressed the entire display is read out slowly and is then restored to normal. The readout time for the STORE CRT mode is approximately one second. This completes the check of the PLOTTER modes.

4-15. 1/3-Octave and 1/1 Octave Mode Test (Optional)

If the Option -03 (1/3 and 1/1 octave analysis) Mode is included in your unit, proceed with this test; otherwise, continue with paragraph 4-16.

Place the CURSOR FREQ TYPE switch in the SNGL position. Depress the RESOLUTION 1/3 OCT pushbutton. Verify that the annotation below the lower graticule line indicates 1/3 octave. Verify that the spectrum display appears similar to Fig. 4-5.

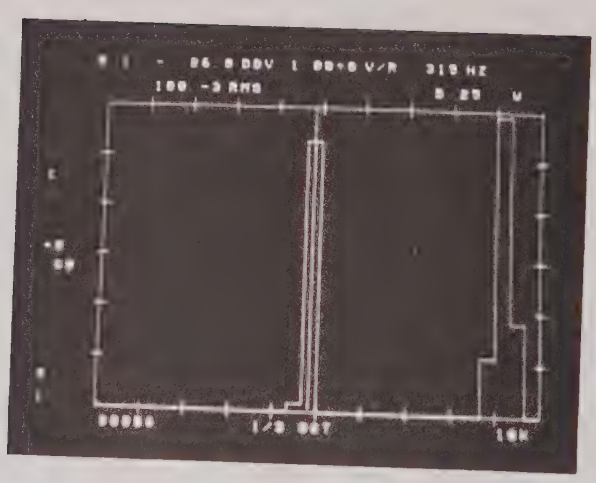


FIGURE 4-5

Notice that there are two well defined spectrum peaks at 1/3 octave band numbers 25 and 38. This can be checked by aligning the cursor with each peak and reading the band number indicated. Depress the 1/1 OCT pushbutton. Verify that the annotation below the lower graticule line reads 1/1 octave and the display appears as in Figure 4-6, below.

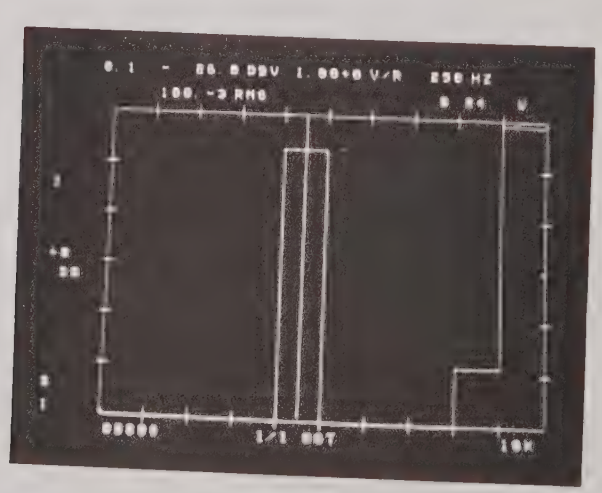


FIGURE 4-6

The two well-defined peaks in the display should appear at octave bands 24 and 39.

Depress the RESOLUTION 400 LINE pushbutton and place the CURSOR TYPE switch to the OFF position.

4-16. INPUT WEIGHTING Check

Place the CURSOR TYPE switch into the SNGL position. Using the CURSOR CONTROL, align the cursor with the spectral line at 6400 Hz. Record the amplitude of the test signal as annotated in the cursor amplitude display field. It should be -20 ±2 dBV. Place the INPUT WEIGHTING control in the A-WT position. The cursor amplitude should decrease by approximately 0.3 dB (e.g., if the original reading was 21.4 dB, the reading with the A-weighting on should be 21.7 dB).

Rotate the FREQUENCY RANGE switch to the positions indicated in Table 4-4. Verify the cursor amplitude readout is within ±2 dB of the levels shown in Table 4-4.

TABLE 4-4

FREQUENCY RANGE	Cursor Amplitude
100,000	50 dB
50,000	37 dB
20,000	25 dB
10,000	20 dB

4-17. Rear Panel Controls

Place the ANNOTATION switch into the GRAT position. Place the CURSOR TYPE switch into the OFF position. Verify that all the annotation on the display is off.

Place the ANNOTATION switch into the DATA position. Verify that the graticule disappears leaving only the spectrum display. Return the ANNOTATION switch to the FULL position.

4-18. WEIGHTING WINDOW Switch

Verify that the weighting annotation in the upper right-hand corner of the display reads W (weighted). Place the WEIGHTING WINDOW into the FLAT position. Verify that the weighting annotation now reads U. Depress the AUTO ARM push-button twice. Verify the spectrum looks similar to Fig. 4-7.

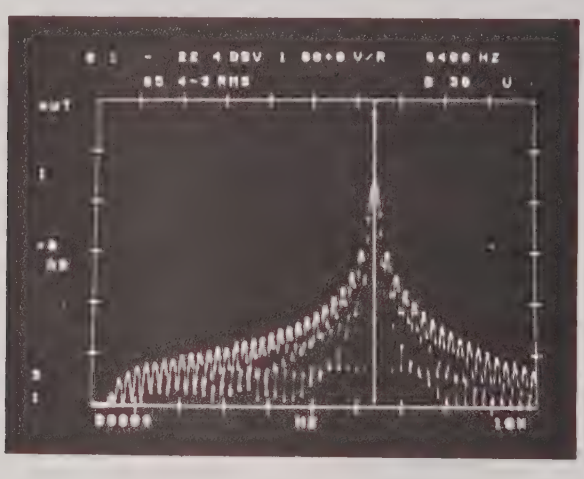


FIGURE 4-7

Place the weighting selector to HANNing. Verify that the display is similar to Fig. 4-8.

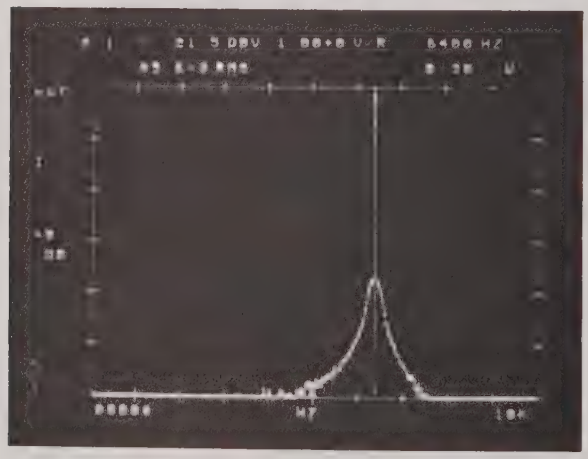


FIGURE 4-8

Place the WEIGHTING WINDOW switch in the AUTO position. Depress the HOLD pushbutton. The HOLDING indicator should be extinguished. Verify that the weighting annotation on the display reads W. Depress the AUTO ARM pushbutton. The weighting annotation should change to U. Depress the HOLD pushbutton. The HOLDING indicator should no longer be illuminated.

If the spectrum analyzer is equipped with a -2 Plug-In containing the Optional Frequency Expansion, perform the following check. If the unit does not contain this option, the operational check has been completed.

4-19. FREQUENCY EXPANSION PLUG-IN

Place the FREQUENCY EXPANSION ORIGIN switch into the INT ORIGIN position. Verify that the EXPAND ON indicator is illuminated. Set the ORIGIN FREQUENCY digital switch to the appropriate setting indicated in Table 4-5 below. Note that the bandwidth of the -2 PLUG-IN filter is annotated in the lower right-hand corner of the display when the expander is ON.

TABLE 4-5

Bandwidth of -2 Filter	Origin Frequency	Cursor Frequency
10 Hz	00000 Hz	6.4 Hz
20	00010	2.8
50	00030	2
100	00060	4
500	00300	20
1000	00600	40
2000	01200	80
10,000	06000	400
20,000	01200	800

Using the CURSOR CONTROL, align the cursor with the spectral line on the display. Verify that the frequency of these spectral lines as read on the cursor frequency annotation field match. The frequency is shown in Table 4-4, above. Place the ORIGIN selection switch into the OFF position.

This completes the check of the -2 EXPANSION PLUG-IN.

SECTION V

444 INTERFACE AND APPLICATIONS

5-1. This section of the report describes aids to understanding and efficient utilization of the Model 444 Mini-Ubiquitous® Spectrum Analyzer. Included are CRT display review, calibration procedures, set-up of analog plotters, power spectral density calibration and measurement, as well as engineering unit calibration. Also included are basic operation of the digital plotter (with 07RS232C Option) and the HP Calculator (with 07HP Option).

5-2. Review of the CRT Displays

This section will review the CRT displays and the meaning of the annotation fields.

A. Time Display (Figure 5-1)

Analyzer input signals, after passing through the input attenuator, and anti-aliasing filter are sampled and converted to digital format by an analog-to-digital converter. These digital samples are stored in a 1024 word input buffer whose contents are periodically interrogated and spectrum analyzed by the FFT processor. When a time display is requested, the 1024 word contents are displayed on the CRT display as shown in Fig. 5-1. The horizontal axis is time divided into eight segments, each representing 128 input samples. The total time is a function of the sampling rate (analysis range). (See front panel.) The vertical scale represents the input full scale range of the A/D converter. This peak-to-peak range is equal to 2.8 X the input sensitivity. Both axes are scaled linearly regardless of the AMPLITUDE/FREQUENCY LIN/LOG switches. In addition no vertical gain is allowed in this display mode and the cursor is inoperative.

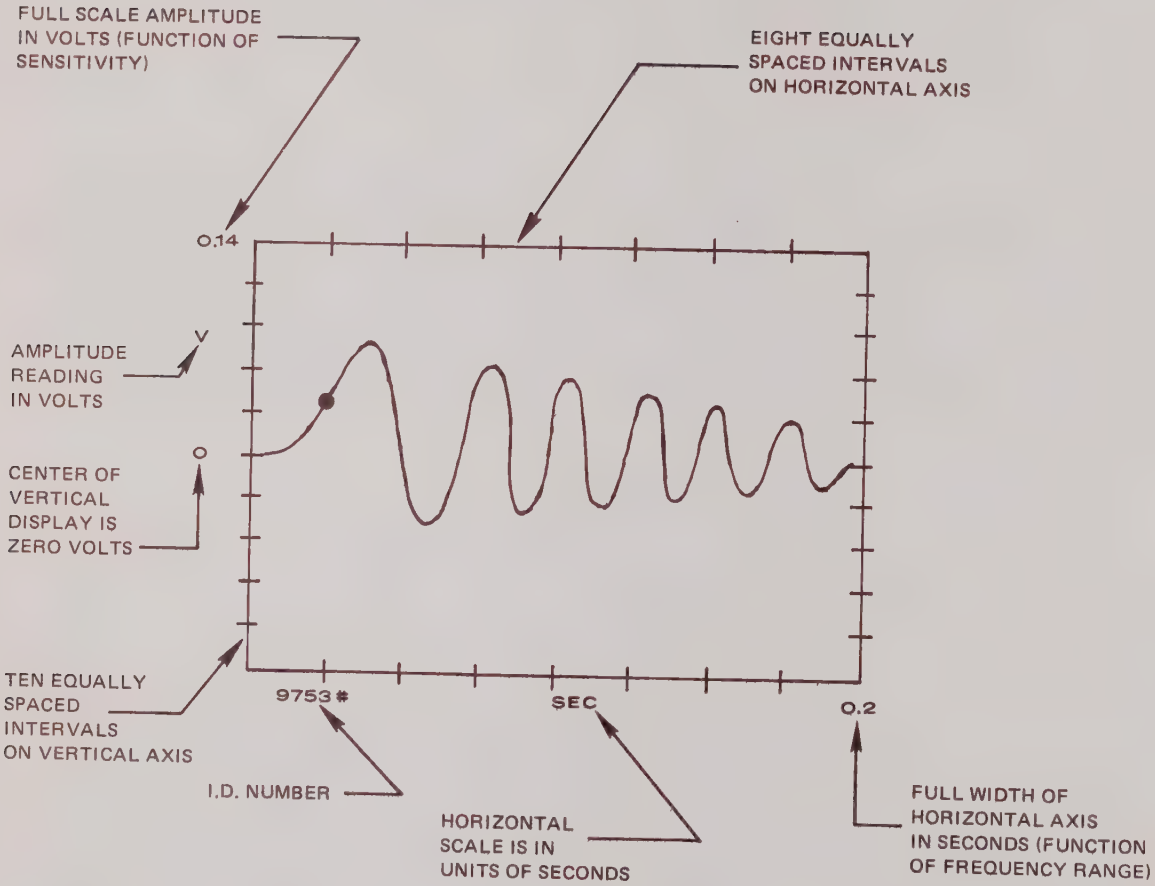

FULL SCALE AMPLITUDE IN VOLTS (FUNCTION OF SENSITIVITY)
EIGHT EQUALLY SPACED INTERVALS ON HORIZONTAL AXIS
0.14
AMPLITUDE READING IN VOLTS
V
CENTER OF VERTICAL DISPLAY IS ZERO VOLTS
0
TEN EQUALLY SPACED INTERVALS ON VERTICAL AXIS
9753#
I.D. NUMBER
SEC
HORIZONTAL SCALE IS IN UNITS OF SECONDS
0.2
FULL WIDTH OF HORIZONTAL AXIS IN SECONDS (FUNCTION OF FREQUENCY RANGE)

Figure 5-1. Time Display

Since samples are normally continuously added to the buffer, the viewing of the time display will normally be unsynchronized. (Signal will appear to slide through the display.) In the hold condition (or after transient capture) no update of the buffer takes place and the display is "frozen".

When a hold condition occurs as a result of a transient capture operation, the intensified dot at the 128 sample (1/8 total time) location corresponds to the trigger point. Both pre and post trigger signal states are visible.

The four digit ID number represents the numeric digital switch entry. The ID number represents the origin frequency of the translated band when used with the -2 option.

B. Single Spectrum Displays (Figure 5-2)

All single spectrum displays have the following in common:

1. Frequency axis represented by Hz or Log Hz and the frequency range.

2. Vertical scale gain/attenuation factor and format (linear = X or /; logarithmic = dB).

3. The input full scale sensitivity of the analyzer.

4. What spectrum is on display, such as instantaneous, averager A or B.

5. If averaged data, the type of averaging and the and the number.

6. Input A weighting (A-WT) if activated.

7. Time domain weighting - W = weighted
   U = uniform

8. ID number

In addition, if the cursor type switch is activated (single or harmonic) then the following is added to the display:

9. Total rms value of the signal in the analysis range

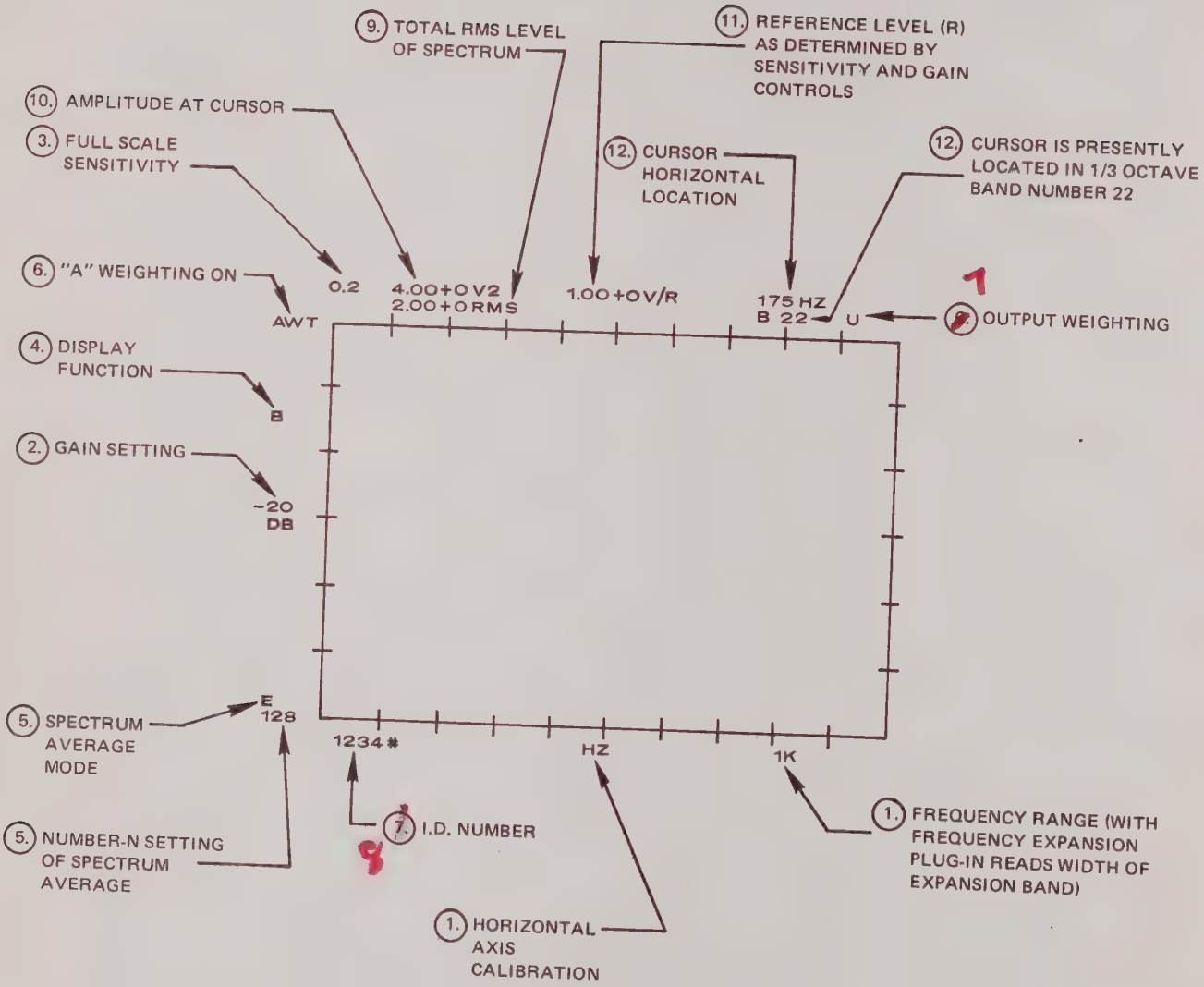


Figure 5-2. Single Spectrum Display

10. Amplitude of the signal at the cursor location in appropriate units.

11. Calibration constant V/R

12. Frequency (or CPM) of signal at cursor location as well as the equivalent 1/3 octave band number.

The top of the display (full scale) is expressed by the following:

In volts	$\frac{\text{Sensitivity}}{\text{GAIN}}$	Thus, the top of the display is equal to 1/4 volt if the sensitivity is one volt rms and the gain is X4
In volts^2	$\left(\frac{\text{Sensitivity}}{\text{GAIN}}\right)^2$	For the above example, full scale is $1/16V^2$.
In dBV	dBV - dB GAIN	If the input sensitivity is 0 dBV and the gain is +20 dB, full scale corresponds to 0 dBV - [+20 dB] = -20dBV.

It is easier however to measure signals directly with the cursor and obtain readings in V, V^2 dBV or R, R^2 or dBR. More will be presented on this topic later.

C. Dual Spectrum Displays (Figure 5-3)

Dual spectrum displays have the following:

1. Frequency axis represented by Hz or Log Hz, and the frequency range.

2. Vertical scale gain/attenuation factor and format (linear = X or /, logarithmic = dB).

3. Two full scale sensitivities; one for each spectrum displayed and representing the value of the input sensitivity of the time that spectrum was generated.

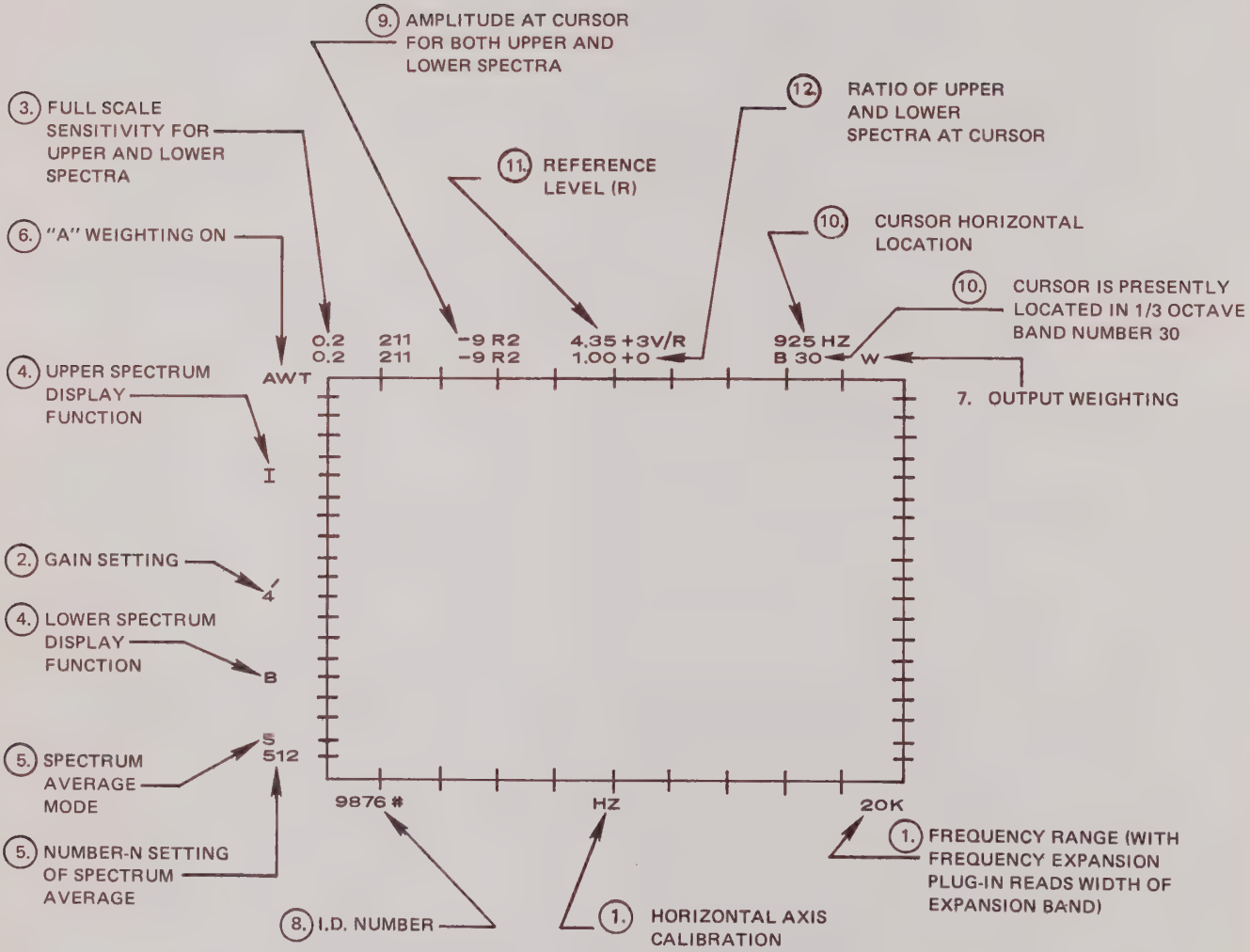

9. AMPLITUDE AT CURSOR FOR BOTH UPPER AND LOWER SPECTRA
12. RATIO OF UPPER AND LOWER SPECTRA AT CURSOR
3. FULL SCALE SENSITIVITY FOR UPPER AND LOWER SPECTRA
11. REFERENCE LEVEL (R)
6. "A" WEIGHTING ON
10. CURSOR HORIZONTAL LOCATION
10. CURSOR IS PRESENTLY LOCATED IN 1/3 OCTAVE BAND NUMBER 30
0.2 211 -9 R2 4.35 +3V/R
0.2 211 -9 R2 1.00 +0
925 HZ
B 30 W
AWT
4. UPPER SPECTRUM DISPLAY FUNCTION
7. OUTPUT WEIGHTING
I
2. GAIN SETTING
4
4. LOWER SPECTRUM DISPLAY FUNCTION
B
5
512
5. SPECTRUM AVERAGE MODE
5. NUMBER-N SETTING OF SPECTRUM AVERAGE
9876 #
HZ
20K
1. FREQUENCY RANGE (WITH FREQUENCY EXPANSION PLUG-IN READS WIDTH OF EXPANSION BAND)
8. I.D. NUMBER
1. HORIZONTAL AXIS CALIBRATION

Figure 5-3. Dual Spectrum Display

4. What spectrum is on display, such as instantaneous, averaged A or B. Upper and lower traces have their own identification.

5. If averaged data, the type of averaging and the number (of the active memory only).

6. Input A-WT if activated.

7. Time domain weighting - W = weighted
   U = uniform

8. ID number

When the cursor is activated, six additional quantities are displayed.

9. Two amplitudes, one for the upper and one for the lower trace representing spectrum amplitudes at the cursor location.

10. Two frequency readings, one in Hertz or CPM, and the other the equivalent 1/3 octave band number.

11. The engineering calibration constant volts/R

12. The ratio of the upper to lower spectrum at the cursor location.

5-3. Use of the Cursor Amplitude (Units and Ref) Switches

The two switches in the CURSOR AMPL section are very important and their use will be described in this section.

REF set to 1V - When the REF switch is set to 1V, and the cursor is activated (CURSOR FREQ TYPE equal to SINGL or HAR) the spectrum amplitude can be measured in volts, volts^2 or dBV, all referred to the input BNC terminal. When the UNITS switch is set to V, the cursor reading will be the equivalent sinusoidal rms input signal that will produce the same spectrum amplitude as that at the cursor location. When the UNITS switch is set to V^2 the equivalent volts^2 input will be displayed.

Note that in all three readings, the equivalent input signal level is displayed, and this reading is independent of display gain. It is also possible to obtain dBV readings even though the display amplitude scales are linear and vice versa.

Relative readings - Often it is desirable to make relative readings using some point on the spectrum as a reference. For this case we need two switch positions, one to tell us we want a relative reading mode and another to permit setting the reference. These are the R and Set R switch positions of the REF switch. This switch is used as follows:

1. Move the cursor to a spectrum frequency location that is to serve as the reference point.

2. Momentarily depress the switch to the SET R position (spring loaded position) and release. The switch will return to the R position and the cursor amplitude readout will be either 1R when UNITS is V
   1R2 when UNITS is V^2
   or 0DBR when UNITS is dB.
   What we have effectively done is to call the cursor location spectrum amplitude unity or 0 dB.

3. If the cursor is now moved to some other location the amplitude readout will be referenced to the reference spectrum point. For example, suppose the amplitude at the new point is 1/10 that of the reference; then the R readings would be

Units		
V	100 -3R	$= \left(\frac{1}{10} R\right)$
V^2	10 -3R2	$= \left(\frac{1}{100} R^2\right)$
dB	-20 dBR	

This is a very convenient feature since it is easy to make relative dB measurements or ratio measurements. If we call the reference one (1), then other locations are read directly in ratios (if units in V).

5-4. Calibration in Engineering Units

In many situations, it is physical engineering units which the user wants to measure, such as acceleration (g's), velocity (in/sec), displacement (mils), pressure (lbs/in), etc. A typical configuration is shown in Fig. 5-4. Here the engineering units say acceleration (g's) is converted to voltage through a transducer with sensitivity of K volts/g. To provide additional drive, perhaps a signal amplifier of gain B increases the signal level. Thus the conversion factor is KB volts/g. Suppose K = 5 mv/g and B is 20. Then KB = 100 mv/g. How can we calibrate the 444 to read directly in g's or engineering units. We can guess that we should set the calibration constant to 100 -3V/R. If you guessed, you are correct. But how do we set the V/R ratio?

1. In the CURSOR AMPL switch group, set the UNITS switch to V.

2. Hold the REF switch to the SET R position. Do not release.

3. Simultaneously move the GAIN switch to INCR or DECR. The V/R constant will change. (INCR will cause the V/R constant to decrease and DECR will cause the V/R constant to increase.) Using the GAIN switch you can single step until the correct V/R value is achieved. When the correct value has been achieved, in this case 100 -3V/R, release the GAIN switch and the SET R REF. The system is now calibrated to read directly in g's (R units). A 3g signal will read 3R (in V), $9R^2$ (in V^2) and 9.54 dBR (in dBV).

Suppose on the other hand you do not have a conversion scale constant. Instead, you have a live signal whose calibration you know; for example, a signal known to be equal to 114 dB. To calibrate the system we proceed as follows:

1. Apply this signal to the analyzer and set the input sensitivity to avoid overload.

2. Move the cursor to the spectral location.

3. Select UNITS to read dB.

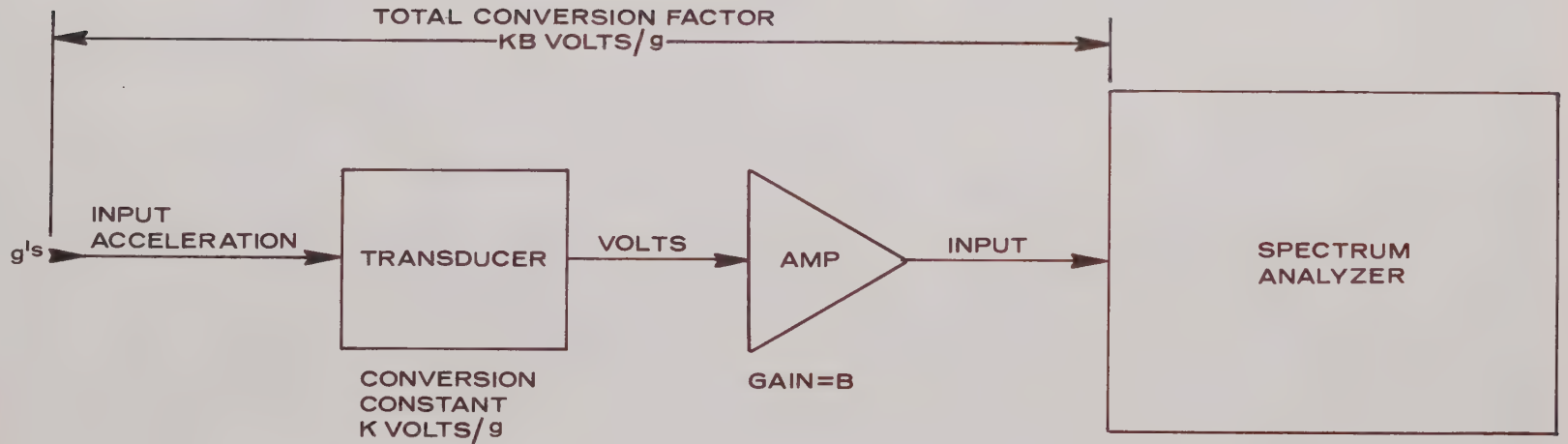


Figure 5-4. Conversion Factor Diagram

4. Hold down the REF switch in the SET Ref position and operate the GAIN switch to cause the amplitude reading to read 114 dBR. Release the REF switch. The system is now calibrated in terms of dB referenced to the live input signal.

It should be noted that we can just as easily calibrate in terms of R or R2. Thus, if the live signal were equal to 14 mils we would set the cursor reading to 14R in the V position of the UNITS switch. If it were equal to $16g^2$ we would set the cursor reading to 16R2 in the V^2 position of the UNITS switch.

5-5. Power Spectral Density Measurement and Calibration on CRT Display

By means of the V/R calibration constant, it is possible to measure power spectral density (V^2/Hz) or spectral density ($V/\sqrt{Hz}$) directly with the cursor.

In the measurement of "random" signals, whose spectral content is distributed rather then concentrated in narrow regions, it is useful to describe the spectrum in terms of a density distribution normalized to one Hertz. By so defining the spectrum, the analyzer resolution or bandwidth must be taken into account. It can be shown that the output power at a particular frequency cell in the spectrum generated by a FFT processor is equal to

$$V^2 out = V^2/Hz \times B_n, \text{ where } B_n = \text{system noise bandwidth,}$$

that is, the spectrum output is equal to the power spectral density times the noise bandwidth of the analyzer filter. For the Model 444 Analyzer the noise bandwidth is equal to

$$\frac{\text{Analysis Range}}{400} \times K$$

where: K_u = unity for uniform input weighting

K_w = 1.5 for weighted input weighting

To determine the PSD (V^2/Hz) or spectral density ($V/\sqrt{Hz}$) it is necessary to set the V/R constant to the proper value as shown in Table 1. To measure PSD directly using the cursor, proceed as follows:

1. Select the proper calibration constant for the analysis range selected and the weighting used. (Table 1.)

2. With the SET R and GAIN switch set the V/R calibration constant to be equal to the set value. For example, for the 5 kHz range and W weighting the V/R constant is 4.33. Set V/R to read 4.33+0.

3. Perform the spectrum measurement using averaged data. Since spectral density measurements are used for random data, sufficient averaging of spectrum data must be performed to generate a good (statistically stable) spectrum.

4. To read PSD set the UNITS switch to V^2. The amplitude readings (R2) correspond to PSD values (V^2/Hz).

5. Set the UNITS switch to V and the amplitude readings are spectral density $V/\sqrt{Hz}$.

6. Set the UNITS switch to dB and the reading is dB with respect to $1V/\sqrt{Hz}$.

It should be noted that because of the anti-aliasing filter ripple, the accuracy of the PSD measurements is limited to the filter ripple approximately $\pm 1/2$ dB except ± 1 dB on 100 kHz range.

To determine density in engineering units, for example g^2/Hz, multiply the V/R engineering unit constant by the set V/R number from Table 1. Thus, if we had a 100 mv/g engineering constant and we operated on 5 kHz with weighted inputs, we would reset V/R to 100 mv/g X 4.33 = 433 -3V/R. Now if the UNITS switch is set to V^2 the cursor reading will be in g^2/Hz.

TABLE 1
444 PSD Measurements Using Cursor

Range	Resolution and Uniform Noise Bandwidth B_u (Hz)	Weighted Noise Bandwidth B_n (Hz)	Set V/R to Uniform	Set V/R to Weighted
100 kHz	250	375	15.8 +0	19.36 +0
50	125	188	11.2 +0	13.7 +0
20	50	75	7.07 +0	8.66 +0
10	25	38	5.00 +0	6.12 +0
5	12.5	18.8	3.54 +0	4.33 +0
2	5	7.5	2.25 +0	2.74 +0
1	2.5	3.8	1.58 +0	1.94 +0
500 Hz	1.25	1.88	1.12 +0	1.37 +0
200	.5	.75	707 -3	866 -3
100	.25	.38	500 -3	612 -3
50	.125	.188	354 -3	433 -3
20	.05	.075	225 -3	274 -3
10	.025	.038	158 -3	194 -3
5	.0125	.0188	112 -3	137 -3
2	.005	.0075	70.7 -3	86.6 -3
1	.0025	.0038	50.0 -3	61.2 -3

5-6. Analog Plotter Interface and Calibration

This section will describe interfacing of an analog X-Y plotter to the Model 444 and its calibration.

A. Interface

To interface with an X-Y plotter, it is simply necessary to connect the X-Y TO PLOTTER outputs at the rear of the 444 to the corresponding inputs of the plotter. The pen lift can be used if the plotter is equipped with a corresponding input command. Otherwise, the pen must be manually lowered or raised in the plot mode.

B. Calibration of an X-Y Plotter without the Use of an External Calibration Signal

The object of plotting is to have a hardcopy of either the time or spectrum data on a set of axes determined by the user and the type of plotter paper available. The calibration procedure is to see that the origin and the maximum excursions in both the horizontal and vertical direction line up with proper points on the plotter paper.

To calibrate the analog plotter, the spectrum analyzer can operate in three calibration modes which can be of use to the operator. These three modes are called the PLOTTER ORIGIN, PLOTTER FULL SCALE, and PLOTTER AT CURSOR. In each mode, DC calibration signals are available as shown in Fig. 5-5.

1. PLOTTER ORIGIN - When this button (on the 444) is depressed, the analyzer feeds out two analog signals, one for the vertical and one for the horizontal, to the plotter, which defines the lower left-hand graticule location of the CRT display. These voltages are close to zero volts.

2. PLOTTER FULL SCALE - When this button is depressed, the analyzer feeds out the vertical and horizontal voltages corresponding to the upper right-hand corner of the graticule display, typically +3.2 volts.

3. PLOTTER AT CURS - If the PLOTTER AT CURSor button is depressed, the analyzer feeds out two analog signals that correspond to the vertical and horizontal deflection of the point which is intensified at the cursor location. As the

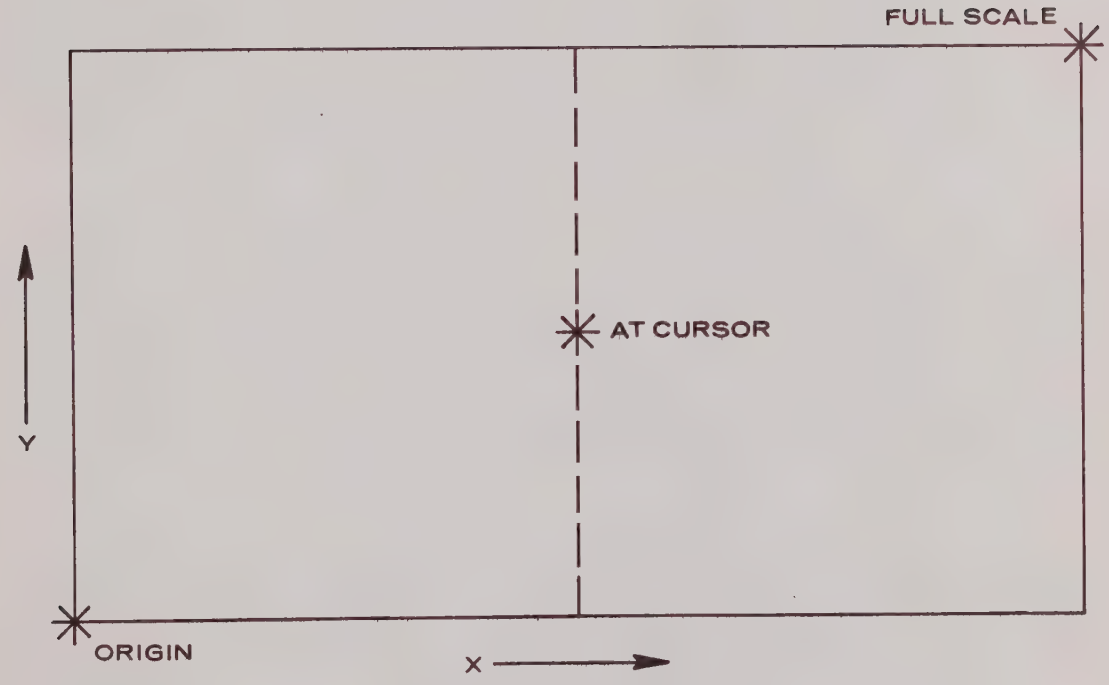


Figure 5-5. DC Level Calibration Locations

cursor location is changed, the horizontal and vertical amplitude (if a signal is present) will change. It is possible then to develop two DC voltages corresponding to a unique point on a spectrum display.

Let us now try to calibrate an analog plot in which the vertical axis is divided into five divisions and the horizontal axis is to be on a logarithmic display. How does one go about plotting a spectrum on this type of paper? Suppose the full scale sensitivity of the analyzer is set for 500 millivolts and the analysis range is 10 kHz. The way to calibrate this plot is as follows:

1. The user must define where he wants the 10 kHz frequency point to appear, and where the upper line of his display is on the paper. Having thus defined these two points, the user has in effect defined the full scale (upper-right) location.

2. The user will then locate where the lower left-hand corner is; namely, where zero amplitude and a frequency of 1/400 of full scale is located. On a log horizontal display the analyzer can present only 400 distinct points. The upper one being 10,000, the lower one being one resolution element or 10,000 divided by 400 or 25 Hz. The user then defines on his log paper where 25 Hz is, having already defined where 10 kHz was initially.

3. It is now only necessary to get the origin point of the CRT display to line up at the origin point of the plotter paper and the full scale to line up on the full scale of the paper. The way to proceed is to first press the ORIGIN button and use the X-Y offset controls of the plotter to locate the orign point. Then press PLOTTER FULL SCALE and adjust the vertical and horizontal gain controls on the plotter until the pen is at the full scale location. It will be necessary to go back and forth between the plotter origin and plotter full scale positions until the plot lines up correctly with those two end points, each time making slight gain and offset adjustments.

4. To make sure that the log horizontal axis is properly calibrated, it is possible to use the plotter at cursor mode. Press the PLOTTER AT CURSor button and set the cursor to the 1000 Hz resolution element. The pen should now

move to the 1000 Hz location on the horizontal frequency axis. The amplitude would correspond to the amplitude that is on the display which may not be defined at this moment. It is thus possible to use the AT CURSor location for frequency axis calibration at any time. The vertical amplitude will be used at a later time when we discuss calibration with an external calibration signal.

The procedure just outlined permits one to transfer a spectrum or time, CRT display onto pre-printed (or defined) analog plotter paper. The procedures would be the same using a log amplitude or a log linear horizontal axis or combinations of the two. The full scale value of the plotter is related to input sensitivity and gain settings as shown by lines 1, 2, 3 of Table 2.

C. Calibration in Engineering Units without an External Calibration Signal

The above procedure describes how to calibrate a plotter in terms of voltages. However, if it turns out that a scale constant is available to convert from voltage to engineering units, it is possible to calibrate the analog plot in terms of engineering units. Using the above example, suppose that the scale factor were 120 millivolts/g. The first thing we know is that since the full scale sensitivity is 500 millivolts, the full scale display in g's would be equal to 500 divided by 120 millivolts or 4.17 g divided by the gain factor. Assume the gain is 1. Unfortunately, the paper was divided into five vertical lines and making the top or 5th line 4.17 g would make each of the other lines an oddball reading. Therefore, what we would like to do is to let the 5th line correspond to 5 g. Therefore, when we press the full scale button we should line up the vertical axis to correspond to 4.17 divisions on the paper. Similarly, when we press the PLOTTER ORIGIN button, the vertical amplitude will be zero and the frequency will correspond again as before to 25 Hz. In setting up the output display in this way we find that each of the major divisions of the plotter paper corresponds to 1 g and the plot is calibrated in terms of engineering units without the use of an external calibration signal. Table 2, lines 4, 5, 6 indicate full scale settings in engineering units given the V/R factor.

TABLE 2
Full Scale Display Readings

1.	In Vrms	$\frac{\text{Sensitivity}}{\text{GAIN}}$	i.e. $\frac{2V}{4}$ = 1/2 Vrms
2.	In $Vrms^2$	$\left(\frac{\text{Sensitivity}}{\text{GAIN}}\right)^2$	i.e. $\left(\frac{2V}{4}\right)^2$ = 1/4 $Vrms^2$
3.	In dBV	dBV- GAIN	i.e. +6dBV- +20 = -14dBV = 200 mV
4.	In R	$\frac{\text{Sensitivity}}{(V/R) \cdot (\text{GAIN})}$	i.e. $\frac{500mV}{120mV/Rx1}$ = 4.17R
5.	In R^2	$\left(\frac{\text{Sensitivity}}{(V/R) \cdot (\text{GAIN})}\right)^2$	i.e. $\left(\frac{500mV}{120mV/Rx1}\right)^2$ = 17.39R^2
6.	In dBR	dBV- GAIN -20 $\log_{10}$ V/R	i.e. -6dB - 0 -[-18.42] = +12.42 dBR (4.17R)
7.	In V^2/Hz	Reading 2 divided by B_n	
8.	In R^2/Hz	Reading 5 divided by B_n	
9.	In dB(V/$\sqrt{}$Hz)	Subtract 10 $\log_{10}$ B_n from 3	
10.	In dB(R/$\sqrt{}$Hz)	Subtract 10 $\log_{10}$ B_n from 6	

B_n = Noise Bandwidth of Analyzer Filter

D. Some Other Calibrations

Other calibrations possible are:

PSD - Table 3 presents the full scale PSD and spectral density values for all analysis ranges and 1Vrms sensitivity. The general full scale value is:

$$\text{Full Scale PSD (Table 3)} \times \text{Sensitivity}^2 \times \frac{1}{(\text{GAIN})^2} = \text{PSD}_{V^2/\text{Hz}}$$

$$\text{Full Scale Spectral Density (Table 3)} \times \text{Sensitivity} \times \frac{1}{\text{GAIN}}$$

$$= \text{Spectral Density } V/\sqrt{\text{Hz}}$$

Density displays are generally displayed on logarithmic amplitude scales. Similar to the engineering calibration we would like to keep the vertical scale paper divisions nice-reading numbers. Therefore, in using six decade (60 dB) paper, we would line up the full scale value calculated above to the appropriate division. For example, with a gain of two, weighted and 200mV rms input sensitivity on 5 kHz, the full scale PSD value is $5.3 \times 10^{-2}\ V^2/\text{Hz}$. Therefore line up the full scale vertical pen position to the 5.3×10^{-2} line on the paper. The origin corresponds to 5.3×10^{-2} -60 dB = $5.3 \times 10^{-8} V^2/\text{Hz}$.

PSD in Engineering Units - Can we calibrate our plotter in terms of engineering unit density scales? Yes. Since we know the full scale value in terms of V^2/Hz or $V/\sqrt{\text{Hz}}$ we must divide these values by $(V/R)^2$ and (V/R) respectively to get full scale R^2/Hz and $R/\sqrt{\text{Hz}}$ values. Calibration would proceed as above.

E. Calibration of an X-Y Plotter Using an External Calibration Signal

The vertical axis of a plot can be calibrated by means of an external calibration signal. The horizontal frequency axis is still determined by the internal calibration of the analyzer. Therefore, the technique used for calibrating an X-Y plotter is to first calibrate the upper and lower frequency points using the origin and full scale signals from the analyzer. Having adjusted the horizontal gain and offset control properly, the vertical amplitude is adjusted by means of the external calibration signal.

TABLE 3
Full Scale Power Spectral and Spectral Density Values
(Based on 1Vrms Input Sensitivity)

Frequency	Unweighted V/√Hz	Unweighted V^2/Hz	Weighted V/√Hz	Weighted V^2/Hz
100 kHz	6.32 -2	40.0 -4	5.17 -2	26.7 -4
50	8.94 -2	80.0 -4	7.3 -2	53.3 -4
20	1.41 -1	2.0 -2	1.03 -1	1.06 -2
10	2 -1	4.0 -2	1.63 -1	2.67 -2
5	2.83 -1	8.0 -2	2.3 -1	5.33 -2
2	4.47 -1	20 -2	3.26 -1	10.6 -2
1	6.32 -1	40 -2	5.17 -1	26.7 -2
500 Hz	8.94 -1	80 -2	7.3 -1	53.3 -2
200	1.41 +0	2 +0	1.03 +0	1.06 +0
100	2 +0	4 +0	1.63 +0	2.67 +0
50	2.83 +0	8 +0	2.3 +0	5.33 +0
20	4.47 +0	20 +0	3.26 +0	10.6 +0
10	6.32 +0	40 +0	5.17 +0	26.7 +0
5	8.94 +0	80 +0	7.3 +0	53.3 +0
2	14.14 +0	200 +0	10.3 +0	106 +0
1	+0	400 +0	16.3 +0	267 +0

When using an external calibration signal, the operator knows that the vertical amplitude of this signal corresponds to either some voltage or engineering unit or some power spectral density. What we want to do in calibrating the plotter using this signal is to have the vertical amplitude scale correspond to that which the operator would like to set up on the paper.

Let us, for example, assume that an input signal is available whose amplitude is 14.6 g. The operator would select the appropriate analysis range and input sensitivity so that this signal will appear as a spectrum line without distortion. Perhaps some averaging would be desirable in case the amplitude of the signal varies slightly. The operator would then place the cursor at the peak of that calibration signal and press the PLOTTER AT CURSor switch. The plotter vertical deflection will then correspond to the 14.6 g calibration signal. The operator would then set the pen to read approximately 14.6 g on his scale. If he presses the PLOTTER ORIGIN button, the vertical displacement would go to zero. Flipping back and forth between PLOTTER ORIGIN and PLOTTER AT CURSor it is possible to get a vertical paper deflection corresponding to zero and 14.6 g, respectively. The plotter is now calibrated directly in g's. Similarly, if it turned out the sinusoidal signal were calibrated in g^2 or other quantities, this same procedure could occur.

If the vertical scale is logarithmic, then we would like to have a major vertical division correspond to so many dB. In this situation what we do is put the cursor at the peak of the signal and vary the signal amplitude by 20 dB by means of the display GAIN control. The deflection of the plotter pen corresponds then to 20 dB. If the operator has selected a certain vertical distance to correspond to 20 dB, then by means of the vertical gain and offset control the operator should be able to get the correct deflection on paper when the display gain is changed by 20 dB.

Suppose now that the full scale input of that calibration signal corresponds to 94 dB. Having adjusted the vertical displacement gain control to give a 20 dB deflection when the display gain changes by 20 dB, it is necessary to use the vertical <u>offset</u> control to move the pen to a position which corresponds to 94 dB on the vertical scale. If the operator

had selected six divisions, each division corresponding to 20 dB, then the top scale could be marked 120, the bottom 0 dB. The calibration signal which corresponds to 94 dB would be made to line up with a 94 dB mark on the vertical scale of the paper.

Thus, it is possible to calibrate vertical axis either without a calibration signal based on the input sensitivity of the spectrum analyzer as presented in the earlier section, or it can be set up using a live signal of known amplitude using the PLOTTER AT CURSor controls.

5-7. Operation With Tektronix 4662 Digital Plotter (07 RS232 Option)

When the Model 444 includes the 07RS232 Option, software routines are included in the analyzer permitting fully annotated plots to be produced on a Tektronix 4662 plotter.

A. Interfacing

The user must interconnect the two units as shown in Fig. 5-6. This hookup involves the following:

1. Interconnect the Model 444 and Tektronix plotter with a standard RS232 cable.

2. Set the A, B, C, D switches at rear of 4662 plotter to 7222, respectively.

3. Set the baud rate of the 444 analyzer to 600. This is accomplished by setting switch E33 on the encoder board to position 6. To gain access, remove the right side cover. The switch is located on the top front side of the encoder in column 33.

4. Set E34 to the zero position (adjacent to E33).

5. Set rear panel mode switch (on the 444) to PLOT position.

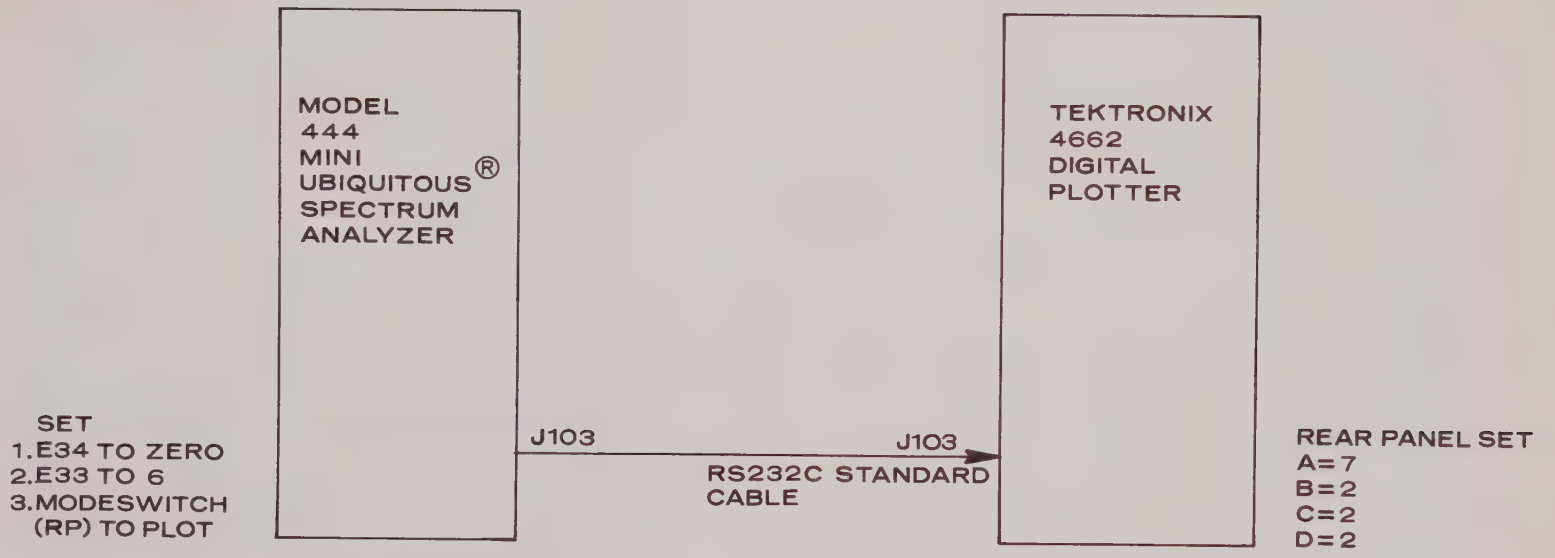


Figure 5-6. Digital Plotter Interface

B. Operation

Set up the correct size plot using the plotter controls. Typical operation would be as follows:

1. To load paper, depress the LOAD button. This releases the paper hold-down. Place the paper onto the plotter bed and align with the bottom and left edges. Release the LOAD button.

2. Set the local switch to LOCAL (depressed).

3. Determine size and location of plot as follows:

a. Using cursor, move pen to where lower left of plot should be. Press the SET LOWER LEFT button until a beep is heard. Move cursor to upper right side of the plot area. Press SET UPPER RIGHT button until beep is heard.

b. Verify proper location of plot area by pressing LOCATE LOWER LEFT and UPPER RIGHT buttons alternately. These buttons cause the pen to be located at the SET positions.

4. Release the LOCAL button.

5. Plotter is ready to plot.

6. Press the STORE CRT button on the Model 444. A plot will automatically be plotted with all the information presented on the CRT display. When the plot is completed, the pen will be in an up position and located where the last vector was drawn. To remove the paper, press LOCAL and LOAD. The former keeps the 4662 under local operator control and the LOAD causes the pen to be moved to the upper right position of the plotter bed, (out of the way) and releases the electrostatic paper hold-down.

5-8. Operation With a HP 9825A Calculator (07 HP Option)

To interface the Model 444 to a HP 9825A calculator requires the following:

A. HP 9825A calculator with the following:

1. HP 98213A "General I/O-Extended I/O"

2. HP 98210A "String-Advanced Programming"

3. HP OPT 001 "15,038 total bytes memory" (recommended)

4. HP 98032A Cable/Logic

B. Model 444 with 07 HP Option

C. Item 4 above, wired and provided with mating connectors to plug into J101 and J102 of analyzer

The interface requires 20 basic signal lines between the calculator and analyzer; these are:

1. 8-bit input (to analyzer bus)

2. 8-bit output (from analyzer bus)

3. HP control (444 $\overline{\text{XFLG4}}$ line)

4. HP Flag (444 $\overline{\text{XCTRL}}$ line)

5. HP directional control line (tied to XD 19 line of analyzer) to generate 6/7 or 14/15 code. See interface notes).

6. Ground

When the two units are interfaced as described, it is possible to send byte data to the analyzer. This data can be used to establish control settings, load time data into the input buffer, or instruct the Model 444 to send data to the calculator. The software driver package is the responsibility of the user.

SECTION V-A

INTERFACING TO THE MINI-UBIQUITOUS® MODEL 444 SPECTRUM ANALYZER

5-1A. Scope of This Section

The purpose of this section is to present an overview of the capabilities for interfacing to the Model 444 Spectrum Analyzer. As such, it will permit the reader to determine the type of interface one can use as well as some of its characteristics.

A generalized interface diagram is shown in Figure 5-1A. Two major interface types are possible: analog or digital. Analog connections are made via BNC cable connectors on the rear panel. Digital interface is via three multi-pin connectors: a 25-pin RS232*(J103) connector, and two 50-pin connectors (J101 and J102). A line drawing of the rear panel is shown in Figure 5-2A. Pin assignments and signal titles are presented in the Appendix.

5-2A. Analog Interface

There are basically three types of analog interfaces possible: interface to a display oscilloscope; interface to a storage oscilloscope; and interface to an analog X-Y plotter.

A. Display Oscilloscope - Three BNC connectors, X, Y, and Z, permit connection to an external display oscilloscope to present the same information displayed on the built-in oscilloscope of the spectrum analyzer. Large screen display devices, such as the Hewlett Packard Model 1300 series oscilloscopes, can be used. The signal characteristics of the X, Y, and Z outputs are:

X = 0 to +1 volt nominal

Y = 0 to +1 volt nominal

Z = 0 volts = Beam on
-2 volts = Beam off
(Other Z Axis voltages are available via jumpers)

*Where RS232 is used it refers to RS232C Interface Type D.

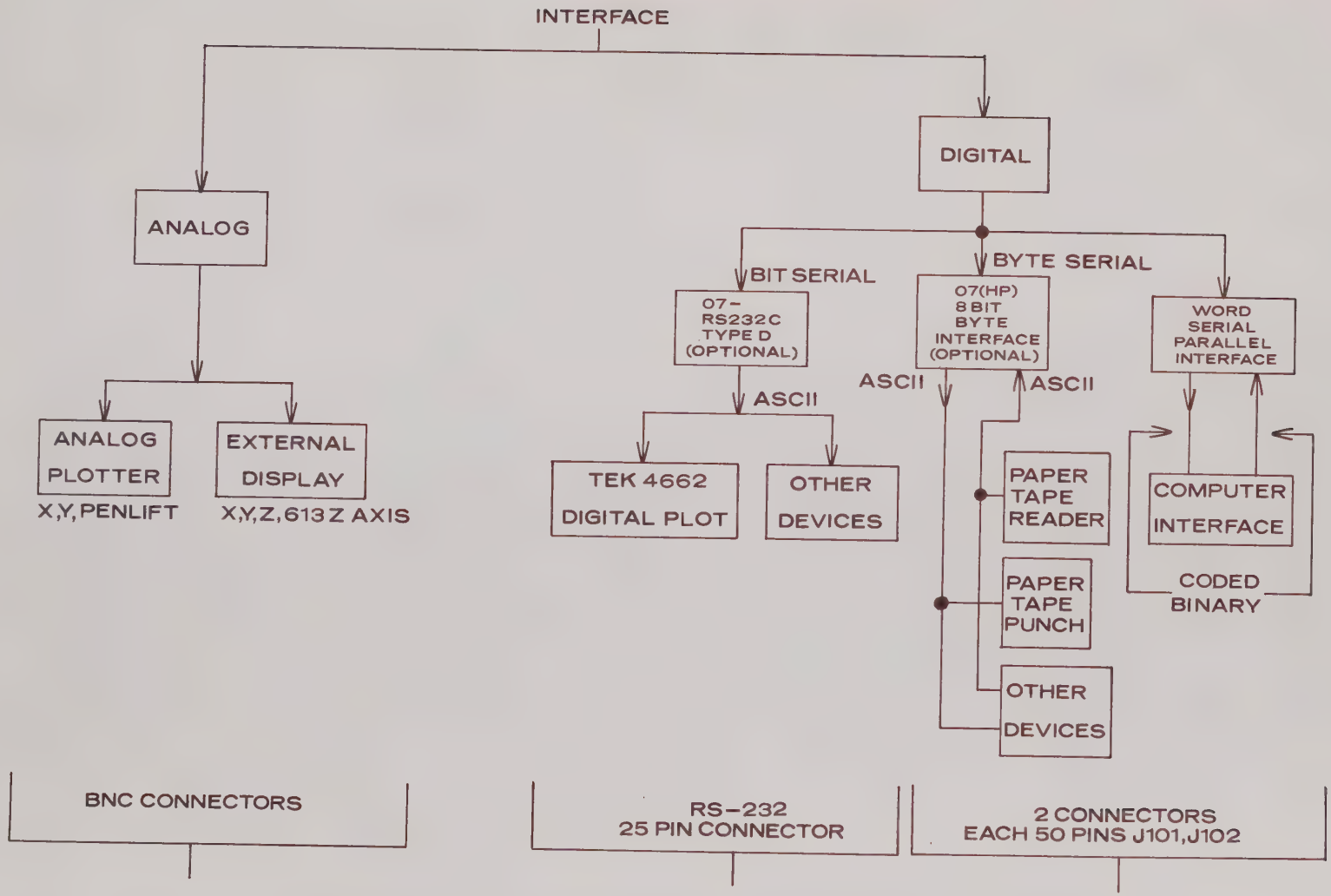


FIG. 5-1A INTERFACE BLOCK DIAGRAM FOR MODEL 444A MINI-UBIQUITOUS® ANALYZER

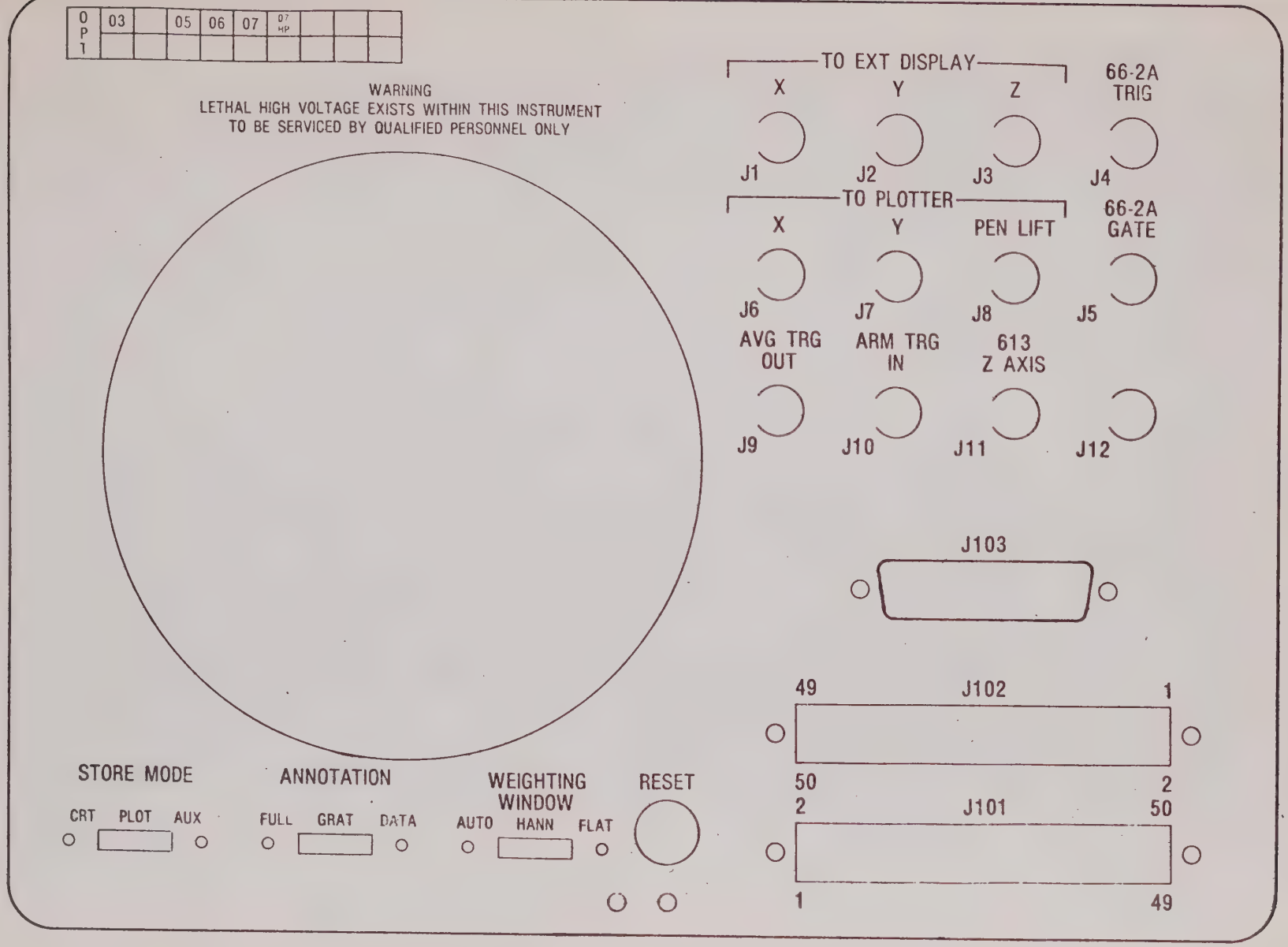


FIG5-2A REAR PANEL VIEW

B. External Display Storage Oscilloscopes - For storage oscilloscopes, similar to the Tektronix Model 613, a display should occur only once upon command and also more slowly to match the speed of the external device deflection circuits. To write a single display on the storage scope, the STORE CRT button is used. Note: the rear panel switch entitled STORE MODE should be in the CRT position.

When the STORE CRT button is depressed, the analyzer will initiate a single, slower display cycle and paint one display on the storage oscilloscope. To allow only one display to be painted, a separate Z Axis control called 613 Z Axis is used. This control is activated only during the single display cycle. Thus, the analyzer can revert to a normal fast cycle afterward without writing another display on the storage scope (Z Axis control is in "beam off" state during normal display). The characteristics for the outputs are:

X = 0 to +1 volt nominal

Y = 0 to +1 volt nominal

613 Z Axis TTL Low = Beam off
High = Beam on

C. Analog X-Y Plotter - Three separate BNC connectors are used for plotting, entitled Plotter X, Plotter Y, and Pen Lift Outputs. When the plot mode is not activated, the X and Y signals are clamped near zero volts and the Pen Lift signal is open-circuited. The plotter signals present only the spectrum or time signal information. There is no graticule or annotation information. In addition, if a dual display is presented on the oscilloscope, the plot function is disabled in order to prevent an erroneous plot. The signal speed characteristics are such as to allow plotting with ten-inches-per-second plotters. The characteristics of the output signals are:

X = 0 to +3 volts nominal

Y = 0 to +3 volts nominal

Pen Lift Open Contacts - Pen up
Closed Contacts - Pen down

For use and calibration of the plotter, see Section 5-6 of the manual.

5-3A. Digital Interface

Referring to Figure 5-1A, please note that there are basically three types of digital communications possible: bit-serial 07 (RS232) option, byte-serial 07 (HP) option, and parallel. For bit- and byte-serial transmission, ASCII character format is used. For parallel transmission, coded binary format is used. All transmission is via TTL compatible signals, except for the RS232.

Three connectors are used for digital interface. They are as follows: a single 25-pin connector serves for half-duplex bit-serial communication (Digital Plotter), and two 50-pin connectors for either byte-serial (HP Calculator), or parallel communication.

A distinction will be made for digital interface between general purpose, bi-directional interfaces and dedicated interfaces. In the general purpose interface, communication between the analyzer and the external device need not involve prior setting of controls. In dedicated interface, a front panel control initiates the transmission or reception of data, or an internal setting allows operation in a certain mode. For example, to use a paper tape punch, etc., requires setting an internal switch to the punch position. Initially, we will discuss general purpose interface communication.

All three interfaces (bit-serial, byte-serial, and parallel) allow the following:

Sense of front panel settings

Remote control of settings

Load of data into the time buffer of the analyzer

Load of spectrum data into the averager memory

Unload of time buffer data

Unload of spectrum data, and

Unload of real and imaginary spectrum data.

5-4A. Internal Analyzer Word Structure

Although the I/O driver circuits for these three interfaces differ, the information transmitted or received eventually appears on the internal bus of the analyzer in the same format, regardless of the communication used. The basic internal word is a 20-bit word consisting of 16 data or control bits and four tag identification bits. The 4-tag bits indicate what the 16-bit data word represents. Two data word formats exist: one for words sent to the external device, via the data external bus (DX), and one for words received from the device, via the external data bus (XD).

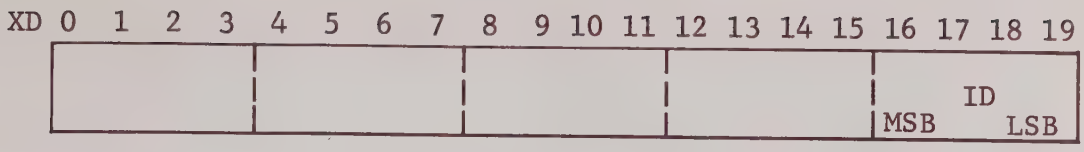
Fig. 5-3A shows the XD bus structure. Sixteen possible combinations of the tag code are listed, indicating what the sixteen remaining bits of the 20-bit word represent. For example, if the tag code is zero, the analyzer will interpret the sixteen data bits as settings for controlling a group of switches on the upper panel. These sixteen bits are coded according to a unique code for those switches. If a code of 5, for example, were received on this bus, the analyzer would interpret the 16-bit field as being 2's complement time data for loading into the input buffer.

Data sent from the Model 444 Analyzer to the external device have formats as shown in Figure 5-4A. Again, if the tag code is zero, the 16-bit field represents information about the setting of certain upper panel controls. In addition, a code 5 would indicate that the 16-bit field contains a single sample of time data from the input buffer.

Obviously, for parallel interface, where all twenty bits can be communicated to the analyzer or external device simultaneously, the codes would be as shown in the figures. However, for bit- and byte-serial interface, the transmission is different.

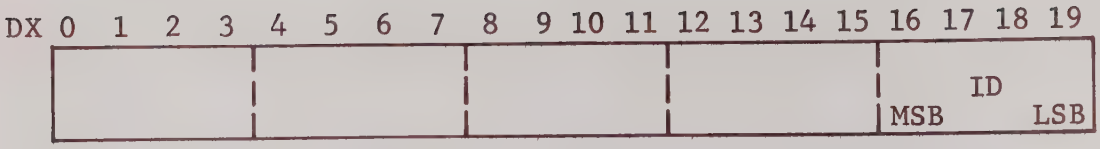
5-5A. Bit-Serial Format

Data sent via the RS232 (Interface Type D) connector consists of ASCII characters. Each ASCII character consists of seven data bits plus parity. Parity is ignored by the Model 444 Analyzer. When data is transmitted via this bus, each ASCII character represents the 4-bit hexadecimal number, 0 through F. To transmit enough information to reconstruct the 20-bit internal analyzer word, five ASCII characters must be transmitted. The



	Decimal	Binary			
		XD16	XD17	XD18	XD19
Control Settings for Upper Panel Group 0	0	0	0	0	0
Control Settings for Lower Panel	1	0	0	0	1
Control Settings for Upper Panel Group 1	2	0	0	1	0
Momentary Controls (i.e., START, STOP, HOLD, etc.)	3	0	0	1	1
Spectrum Data to Averager	4	0	1	0	0
Time Data to Input Buffer	5	0	1	0	1
8-Bit ASCII Data (negative-true)	6	0	1	1	0
Handshake Acknowledge for ASCII Transmission	7	0	1	1	1
Origin Setting for Range Translator	8	1	0	0	0
Reference Voltage Setting	9	1	0	0	1
Display Gain Setting	10	1	0	1	0
Spare	11	1	0	1	1
Cursor Location	12	1	1	0	0
Number of Averages	13	1	1	0	1
8-Bit ASCII (positive-true)	14	1	1	1	0
Handshake Acknowledge for ASCII Transmission	15	1	1	1	1

FIGURE 5-3A. XD BUS TO THE 444 ANALYZER



	Decimal	Binary			
		XD16	XD17	XD18	XD19
Sense Panel Group 0 Settings	0	0	0	0	0
Sense Panel Group 1 Settings	1	0	0	0	1
Sense Panel Group 2 Settings	2	0	0	1	0
Sense Panel Group 3 Settings	3	0	0	1	1
Spectrum Data Output	4	0	1	0	0
Time Data Output	5	0	1	0	1
Real/Imaginary Instanteous Spectrum Data	6	0	1	1	0
Plotter Information	7	0	1	1	1
Translator Origin Frequency	8	1	0	0	0
Reference Voltage Setting	9	1	0	0	1
Display Gain Setting	10	1	0	1	0
Spare	11	1	0	1	1
Cursor Location	12	1	1	0	0
Number of Averages Setting	13	1	1	0	1
Positive Acknowledge (tag only defined)	14	1	1	1	0
Negative Acknowledge (tag only defined)	15	1	1	1	1

FIGURE 5-4A. DX BUS FROM 444 ANALYZER

first four ASCII characters represent the four hexadecimal numbers used to generate the 16-bit data field. The fifth character is the tag character and tells the analyzer what the previous four characters represent. Similarly, when data is sent from the analyzer, the same five ASCII character sequence occurs with the first four characters representing the data and the fifth character representing the tag.

5-6A. Byte-Serial Format

In byte-serial transmission, eight bits (seven ASCII plus one parity) of information are sent simultaneously. These bits are ASCII formatted. Again, it is required that five ASCII characters be sent or received to reconstruct the 20-bit analyzer word. Each ASCII character represents a hexadecimal number from 0 through F.

5-7A. Parallel Format

In parallel interface, the entire 20-bit word is transmitted at once and the coded binary format of the internal analyzer word is used. Hexadecimal and ASCII characters are not used in parallel interfaces.

5-8A. Comments

So far the characteristics of the words transmitted on the bit-serial, byte-serial, and parallel interfaces have been described. It should be noted that bi-directional communication can exist in each of these three interface modes, provided the external device has enough intelligence to encode data, so it can interpret the transmission signals. For example, an RS232 port of a calculator could be used to permit control, sense and data transmission to and from the analyzer. In addition, the byte-serial format could be used by an HP calculator to permit a complete bi-directional communication. The parallel bus would normally be used for high-speed computer interfaces. A digital plotter (similar to the Tektronix 4662), on the other hand, expects to receive the spectrum or time data in the form of end-point vectors. It would not be able to accept the format that exists in our general purpose interface. This unique device requires special formats and controls, and interface to it is described in the Dedicated Digital Interface section.

5-9A. General Purpose Digital Interface Characteristics

A. Bit-Serial (RS232C)

The Model 444 can be interfaced with devices compatible with EIA standard RS232C, Type D. This standard, entitled "Interface Between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange," specifies not only the connector type and pin assignments, but also the signal characteristics for interchange between the two devices. The signals are not TTL. The Model 444 acts as the data communication equipment in the specification, and the external device is the data terminal equipment. The Type D interface requires that the external device send a "Request to Send" signal and that the analyzer respond with a "Clear to Send" signal. The interface uses the J103, 25-pin connector which meets the EIA standard.

Communication can occur at baud rates of 110, 150, 300, 600, 1200, 2400, 4800, and 9600. The baud rate used in the communication is selected by means of a switch internal to the analyzer. (See Appendix).

1. Transmission to the Analyzer - Transmission of ASCII characters to the analyzer must follow the "Request to Send/Clear to Send" protocol. The external device issues a "Request to Send" signal and the analyzer, when ready, responds with a "Clear to Send." A "Request to Send/Clear to Send" handshake occurs with every ASCII character sent. The data format follows the five ASCII character format discussed previously. In addition, the analyzer will recognize a certain set of special single ASCII character controls which the external device can send to perform certain operations. These are listed in Table 5-1A. For example, the transmission of an "S" character to the analyzer will initiate the sending over of all sense information pertaining to the front panel controls. This data includes all 20-bit words with tag numbers 0, 1, 2, 3, 8, 9, 10, 12, 13. A transmission of the letter "T" will send over time or spectrum data, depending upon which is on current display.

If an operator is keying in control information for the analyzer front panel settings, it is sometimes possible to make an error in the keying. Provide that the error did not occur on the fifth and final charcter of the 20-bit word format, hitting the / button will cause the analyzer to ignore the previous four characters.

TABLE 5-1A
ASCII INTERFACE CONTROL FUNCTIONS

Control Character	Functions
R	System master Reset. Entering this character will cause the 444 to be re-initialized.
S	Send Sense data. Entering this character will cause the settings of the 444 controls to be encoded and transmitted from the 444 via the output bus.
T	Send Time or Spectrum data. This character will initiate a transfer of the current display (time or spectrum) to the output bus. (Time data is not available in the 1/3 octave or 1/1 octave modes.)
Q	Send Quadrature (real/imaginary) data. This character will initiate a transfer of the real/ imaginary instantaneous spectrum components to the output bus. (This function is available only in the 400 line mode, while viewing INST or while the averager is running.)
L	Return to Local control. Sending this character will return control of the 444 back to the normal control switches, thus ending the remote control operation.
/	Rubout function. This character will cause current input, five-character group to be rubbed out, provided the entire group is not generated. This is used primarily for correcting errors.
ETX (CNTLC)	Terminate text. This marks the end of a complete data transfer. The 444 analyzer will issue an ETX after each complete transfer.

Referring to Figure 5-3A, if a control setting word is input, say with a tag of 1, the lower panel controls will be automatically placed into remote control. The control settings will remain in their last state unless changed by input data. To come out of remote control, the special character "L" must be sent, restoring local control. This operation also applies to the byte serial ASCII interface described later.

2. Transmission to the External Device - All transmission of data to the external device will occur without "Request to Send/Clear to Send" protocol, since this is used only when the external device talks to the analyzer per RS232 specifications. Also, note that data is output whenever the analyzer is ready. (The external device must be ready.) At the end of a time or spectrum data transmission, the analyzer will append an EXT terminate signal to the data block.

When data is transmitted from the analyzer to a terminal, the characters will be in hexadecimal format and any listing on a CRT terminal will be in that format. An internal analyzer switch will allow transmission of CR (carriage return) and LF (line feed) characters after every 20-bit analyzer word, if desired.

B. Byte-Serial Transmission

The byte-serial transmission uses ASCII characters. Like bit serial, five ASCII characters are sent to generate one internal 20-bit analyzer word. Furthermore, the same special, single character commands are used.

The byte-serial interface uses the same two 50-pin connectors (J101 and J102) as that of the parallel interface. In fact, some of the same data lines are used for both interfaces. On input data, only eight of the sixteen lines are used for the ASCII data. However, to inform the analyzer whether byte-serial or parallel information is on the input lines, the four tag bits on the input connector are used. When input data is to be interpreted as an 8-bit byte, a code of 6 or 14 is placed on these four lines. When a code of 14 is applied, it means the 8-bit byte is to be treated as a positive-true character (that is, a high is one; a low is zero). A code of 6 indicates a negative-true where a low is a one and a high is a zero. We abbreviate this as ASCII (positive-true) and $\overline{\text{ASCII}}$ (negative-true).

Two other signals are required to handshake: an external flag 4 ($\overline{\text{XFLG4}}$) signal and an external control ($\overline{\text{XCTRL}}$) signal. These are used as described in the following paragraphs.

1. Transmission to the Analyzer - When the external device wishes to transmit information to the analyzer, it goes through the following sequences:

a. It places the 8-bit ASCII data on the eight specified lines of the 20-bit XD bus (J101). It places a code of 6 or 14 in the upper four bits, depending on whether the ASCII data is to be treated as negative-true or positive-true. In practice, a 4-bit external input is not necessary to generate the 6 or 14 code. Instead, tie lines XD 16, 17, and 18 to a high or low condition "permanently." However, we must control the last bit (XD 19) to complete the handshake. In this case, low for both 6 and 14.

b. It lowers the $\overline{\text{XFLG4}}$ line to tell the analyzer that data is available.

c. The analyzer, upon sensing that the flag line has been lowered, looks at the bus, recognizes character 6 or 14 in the tag position, and enters the data as an ASCII character.

d. The analyzer lowers the $\overline{\text{XCTRL}}$ line to indicate that it has accepted the data.

e. The external device raises the $\overline{\text{XFLG4}}$ line.

f. After receipt of the $\overline{\text{XFLG4}}$ high condition, the analyzer returns the $\overline{\text{XCTRL}}$ to a high state, indicating that it is ready for another ASCII character.

This is the normal sequence followed for feeding one ASCII character to the Model 444 analyzer. When a group of five ASCII characters are to be transmitted to the analyzer, for example, to set the upper panel controls, the above sequence is repeated five times. For each character, a code of 6 or 14 must be applied to the four lines on J101. Note, however, that the fifth ASCII character still represents the tag which, in this case, is zero and which tells the analyzer that it is the upper panel control information that has just been transmitted.

If a special character, as indicated in Table 5-1A, is sent to the analyzer, it will respond by feeding appropriate data back to the external device, via the output bus. This transmission is described below.

2. Data Transmission from Analyzer to External Device - To send data to the external device, it is necessary to first know that the device is ready. Both positive-true and negative-true data appear simultaneously on the output bus.

Data transmission is initiated only upon receipt of one of the special ASCII characters (Table 5-1A). When the analyzer has received such a character, it waits until the device is ready.

The transmission of an ASCII character proceeds as follows:

a. The device sets a code of 7 or 15 on the input bus tag lines and lowers the $\overline{\text{XFLG4}}$ line signifying it is ready. If the XD 16, 17, and 18 lines were hardwired to the correct 6 or 14 code, then the setting to 7 or 15 merely requires a low to high level change on XD 19. This line is the directional line used in the HP9800 series calculator interface.

b. The analyzer places the ASCII and $\overline{\text{ASCII}}$ characters on the output bus and lowers the $\overline{\text{XCTRL}}$ signal. When the $\overline{\text{XCTRL}}$ line is set to logical "0" (low) the DX bus output is as shown in Figure 5-5A.

c. When the device has accepted the data, it raises the $\overline{\text{XFLG4}}$ signal.

d. The analyzer senses completion of transmission by raising the $\overline{\text{XCTRL}}$ signal.

e. To receive another character, the device goes through Steps a through d.

Again, five ASCII transmissions constitute an analyzer word. To signify the end of the data block, the analyzer will send an ETX at the end of time or spectrum data. Both ASCII and $\overline{\text{ASCII}}$ data are available on the output bus simultaneously.

0 1 2 3 4 5 6 7	8 9 10 11 12 13 14 15	16 17 18 19
MSB $\overline{\text{ASCII DATA}}$ LSB	MSB ASCII DATA LSB	0 0 0 0

FIGURE 5-5A. DX BUS ASSIGNMENT FOR 8-BIT ASCII OUTPUT DURING TIME THAT $\overline{\text{XCTRL}}$ IS AT LOGICAL "0"

C. Parallel Interface

Parallel interface uses the 20-bit wide input (to analyzer) bus XD and the 20-bit wide output (to device) bus DX, both wired to the J101 connector. Data formats used are those shown in Figures 5-3A and 5-4A.

The general purpose parallel interface operates in a handshake mode, using the following signals: A $\overline{\text{DX READ}}$ pulse (indicates data on the output bus is stable) and $\overline{\text{XFLG4}}$ signal, activated by the device when data is available for input.

Remote control of the front panel requires two additional signals, $\overline{\text{XFLG0}}$ and $\overline{\text{XFLG1}}$, indicating that the upper or lower panel, repectively, is to be controlled. When these lines are lowered, the analyzer retains its last state and is locked out from further control from the panel switches. Data sent by the external device can then change the setting status.

1. Transmission of Data to the Analyzer - To send data to the analyzer, the external device places the 20-bit word on the input bus and lowers $\overline{\text{XFLG4}}$ to indicate data is available. The analyzer checks the word. If the tag is an allowed code, it will accept the data and acknowledge this operation by feeding the acknowledge tag 14 (Figure 5-4A) onto the output bus together with a $\overline{\text{DX READ}}$ pulse. If the code is illegal, such as a tag of 11 (SPARE - Figure 5-3A), it will not accept the input word. When this occurs, the analyzer sends a code 15 (not acknowledged) and a $\overline{\text{DX READ}}$ pulse to the output bus. The device will have to check its data and retransmit the data word. Note: When sending remote control data, the appropriate $\overline{\text{XFLG0}}$ or $\overline{\text{XFLG1}}$ line must be held low. Remote control remains activated as long as these lines are held low.

When inputting a block of time data, the first word received by the analyzer will automatically be placed in the first address location of the input memory. Thereafter, each new word will be written into successively higher address locations. The external device must keep track of the number of data words sent. Once a time load has been started, the processing will halt and the analyzer will be dedicated to the external device. It will wait for each new word until the entire transmission has been completed. The maximum input rate is approximately one word per 20 microseconds.

When inputting a block of spectrum data, the first word should contain some front panel settings so that the annotation will appear correct on the CRT screen. The format for the first word is shown below:

X0 1 2 3 4 5 6 7 8 9	10 11 12	13 14 15 16 17 18 19
# of Completed Averages	Sensitivity	
	0 1 2	0 0 0 0 1 0 0

Once this word has been inputted the actual 400 data values can be transmitted. See Appendix for codes.

If the device does not send enough words [(1024 time, or 401 spectrum),(31 if octave)] then the analyzer will hang up waiting for the correct number. Once the required number has been received, processing continues. Sending too many characters is also bad. If, for example, 1025 time points are sent, the analyzer will interpret point 1025 as the start of a new load and will wait for more data. Thus, it is important that the external device keep accurate track of the number of transmissions.

2. Transmission of Data to the External Device- Transmission of data to the external device can be with no handshake or partial handshake. The external bus is actually a buffered version of the internal bus. Once through a complete processing cycle of the analyzer (normally 120 milliseconds) all data useful to the external device will have appeared on the output bus at the analyzer's rate. Data that is allowable for transmission (Figure 5-4A) has a legitimate tag code and a $\overline{\text{DX READ}}$ pulse. Data without both are to be ignored.

The $\overline{\text{DX READ}}$ pulse is two microseconds wide and during this interval data is stable on the output bus. If the external device can sense the tag and strobe the data into its own registers within that two microsecond interval (either edge can be used for strobe), the analyzer processing will not be interrupted and no handshake is required.

For time or spectrum data, the start of the block must be located. This is achieved as follows: The external device senses a tag code of zero (using the DX READ). The first 5 code (time) or 4 code (spectrum) following the zero is the first word of the data block. Thereafter, all time or spectrum data is fed out in sequential order at a rate of approximately 20 microseconds per word. The DX READ pulse indicates when data is stable.

If the external device cannot keep up with the output rate, then a handshake must be used, resulting in a stall of the analyzer. For this operation, the device must decode the tag within the two microsecond DX READ interval. It then lowers an XPADEN line within the two microsecond interval. The analyzer will stop and keep the data word on the output bus until the XPADEN has been raised. In this manner the external device can control the readout rate.

The use of the parallel I/O interface in this mode is the most general purpose and is well adapted for use with intelligent type external devices, such as computers, computer interfaces, etc. There are special parallel interfaces specifically set up for loading data into the analyzer from an external A/D converter or from some other devices which are not as intelligent. These are described in 5-12A.

5-10A. Summary of General Purpose Digital Interface

The general purpose interfaces described in the preceding pages permit an intelligent external device to communicate in a bi-directional mode with the analyzer in three types of transmission: bit-serial, byte-serial, and parallel. In each of these transmission modes, it is assumed that the external device can operate with the special formats used. Note, also, that in these general purpose interfaces, it is the external device which initiates the transmission of data and acts as the controller. No front panel controls on the analyzer were necessary to affect communication with the external device.

The bit-serial format can be used by certain devices which have computational capabilities such as calculators with RS232 inputs. The byte-serial format is the type of format used to interface to the HP 9800 series calculators. The parallel interface can also be used to interface with and HP 9825 calculator, using its parallel bus, or to computers via a computer interface unit.

For those devices which do not have the ability to initiate communication, or for those devices which require special formats, the operator must then make use of the front panel controls located on the analyzer. This type of dedicated digital transmission is covered in the following section.

5-11A. Dedicated Digital Interface Characteristics

In all but one (the 144 tape interface) of the dedicated digital interfaces, the initiation of transmission occurs when the STORE CRT button is activated, and the STORE CRT mode switch on the rear panel is set to AUX or PLOT. Some of the devices requiring dedicated operation are:

RS232 Receive-Only Terminals (AUX)

Tektronix Model 4662 Digital Plotter (PLOT)

Paper Tape Reader (AUX)

Paper Tape Punch (AUX)

NSC Model 144 Tape Recorder (AUX)

Obviously, since a single front panel control button is used to interface to several devices, it is necessary to set up the format of the data transmission as well as to determine which of the three transmission modes will be used. A switch internal to the analyzer determines the device and transmission mode. If a Model 144 tape recorder is hooked to the analyzer and the internal switch is set to communicate with that device, pressing the RECORD button on the Model 144 will cause the entire display to be transferred to the tape recorder via the parallel interface bus. On the other hand, if the Tektronix 4662 digital plotter is used (with rear panel STORE CRT mode switch set to PLOT), pressing the front panel STORE CRT button will cause the present oscilloscope display to be transferred to the digital plotter. The Model 144 analyzer will supply all the vector information necessary to plot the display on this plotter. This format is no longer the same as discussed in the general purpose interface. Operation with these dedicated devices is described in the following pages.

A. RS232 (AUX)

The internal switch allows three settings for RS232 output only communication:

1. Sense and real/imaginary spectrum data

2. Sense and spectrum magnitude or time

3. Sense, real/imaginary spectrum data, and time or spectrum magnitude

In each mode, the STORE CRT initiates transmission and the termination is indicated by an ETX character. The format corresponds to the Figure 5-3A code.

When the first transmission type is selected, the transmission will consist of sending over all the front panel sense information and the real and imaginary components of the instantaneous spectrum.

In the second selected mode, the analyzer will feed over the sense data and either time or spectrum information, depending on which is displayed.

The third selection provides both sense, real/imaginary spectrum data and time or spectrum magnitude, depending on the display.

In all three modes, the analyzer should be placed in a hold state.

NOTE: Time data is not available in 1/3 octave or 1/1 octave modes. Also, real/imaginary data is available only when the analyzer is in the 400 line mode, while viewing.INST or while the averager is updating.

B. Tektronix Model 4662 Digital Plotter (PLOT)

When operating with the Tektronix Model 4664 digital plotter, the analyzer is the sending device and the plotter is the receiver. A complete Type D interface is not used, since it is assumed that the plotter will always be ready to accept

data from the analyzer. Pressing the STORE CRT button initiates the stream of specially formatted data to the plotter. The format is vector, end-point information and does not correspond to Figure 5-3A.

In order not to exceed the rate at which the plotter can process the data, the baud rate is set to 600. The baud rate is selectable, internal to the Model 444 Analyzer.

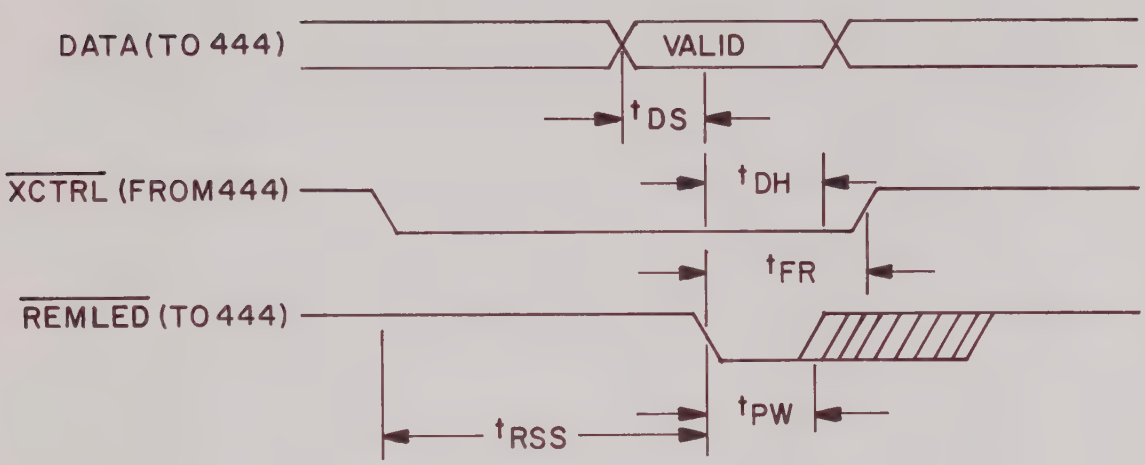
To operate with the Tektronix plotter, interconnect the RS232 cable from the Tektronix to J103 on the analyzer unit. Set the baud rate to 600 (internal to the 444; see page 5-52A), Set the "Ignore Request to Send Protocol" switch E34 to zero position. Set the 444 rear panel STORE CRT mode switch to PLOT. Set the four coded switches, ABCD, on the rear of the Tektronix unit to 7222. The unit is now ready for operation. When the STORE CRT button is depressed, the display presented on the oscilloscope of the Model 444 will be transferred to the Tektronix plotter.

C. Paper Tape Reader (AUX) (See Timing Figure 5-6A)

To interface with the Paper Tape Reader, the analyzer must apply a start reader pulse as well as the necessary handshakes. The byte-serial interface is used with the Paper Tape Reader. Since the reader is a dedicated device, the four tag bits on J101 should be set either to a code of 6, to indicate that the characters are negative-true, or to a code 14, to indicate that the ASCII character transmitted are positive-true. These can be hardwired since acknowledge is not required on these lines. Two other signal lines are used to communicate with the reader: The external control line, $\overline{\text{XCTRL}}$ and the remote line, $\overline{\text{REM LED}}$. If the internal controls on the spectrum analyzer are set for tape reader operation, pressing the STORE CRT button on the spectrum analyzer will cause the $\overline{\text{XCTRL}}$ to go low to start the reader operation. The first ASCII character is then placed on the lines by the reader and the $\overline{\text{REM LED}}$ line is pulled low to indicate that data is stable. When the analyzer has accepted that data, it will raise the $\overline{\text{XCTRL}}$. The reader senses this and $\overline{\text{REM LED}}$ is raised. Another ASCII character can now be read.

Fig. 5-6A

444 - Paper Tape Reader Timing Diagram



Sequence:

1. 444 Lowers XCTRL to Start the Reader
2. Reader Places DATA on XD Bus with Code 6 or Data with Code 14
3. Reader Lowers REM LED to Indicate Valid Data
4. 444 Loads Data and Removes XCTRL
5. Reader Removes REM LED to Indicate Ready

If Reader Does Not Respond to a XCTRL Within 3 Seconds, the Read will be Terminated and XCTRL Removed.

		Min.	Max.
t_{DS}	Data to REM LED Setup	500 nsec	
t_{DH}	REM LED to Data Hold	2.5 μsec	
t_{FR}	XCTRL Response Time		4.0 μsec
t_{PW}	REM LED Pulse Width	2.5 μsec	
t_{RSS}	REM LED Response Time		3 sec

The format for reading data from the tape is the same as the general purpose byte-serial format. Data is in the form of 20-bit analyzer words (five ASCII characters per analyzer word), or the special control symbols like "R", "S", "T", etc. Transmission from the reader to the analyzer will be continued until an ETX ASCII character is sensed by the analyzer or there is no response from the reader within three seconds after the last request for new data.

D. Paper Tape Punch (See Timing Figure 5-7A)

If the user wishes to feed analyzer information to a paper tape punch, then the internal switch settings on the Model 444 analyzer are set to operate in the paper tape punch mode. In this mode of operation, depressing the STORE CRT button will cause transfer of data to the paper tape punch. There are three different data that can be transferred to the punch, depending upon internal switch positions in the analyzer. These three are the same as for the RS232, namely: (a) sense, and real and imaginary spectrum components; (b) sense and spectrum or time data only; (c) sense, real and imaginary spectrum, and spectrum or time. The paper tape punch operates on the handshake basis. When the STORE CRT button is depressed, the Model 444 analyzer puts data on the DX lines. As in the byte-serial operation described previously, both ASCII and $\overline{\text{ASCII}}$ characters are available simultaneously on the output bus.

When data placed on the eight lines is stable, the analyzer will lower the $\overline{\text{XCTRL}}$ line to indicate data is valid. The punch loads the data and lowers the $\overline{\text{REM LED}}$ line to indicate it has punched the data. Upon receipt of this signal, the analyzer removes the data from the lines and raises the $\overline{\text{XCTRL}}$. The punch, in turn, deactivates the $\overline{\text{REM LED}}$. The format is as mentioned before, namely that all data is transmitted as five ASCII characters per analyzer control word.

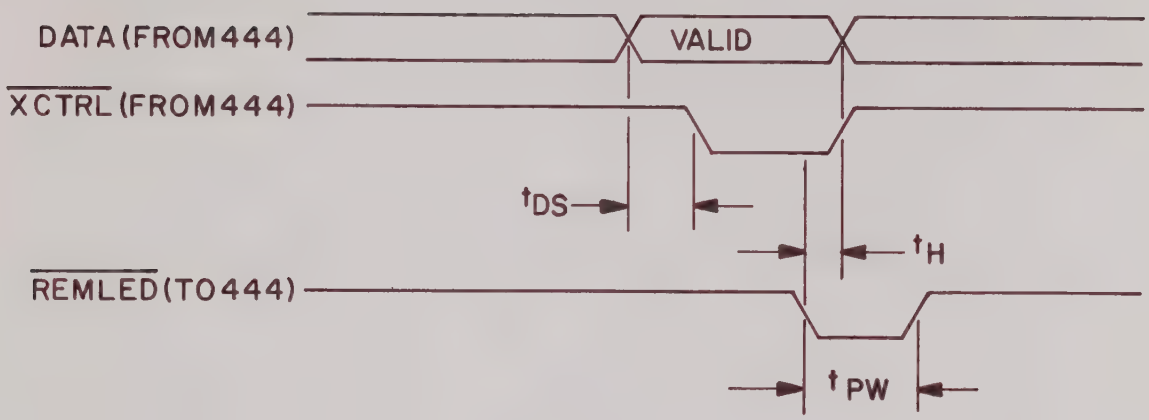
E. Model 144 Tape Recorder (AUX)

Operation with the Model 144 does not require any special settings on the 444. The parallel interface is used.

Setting the select mode switch to the Model 144 setting and installing a special cable between the 444 and the 144 allows a record operation on the 144 to be started each time the STORE CRT button is pressed. This does not interfere with the normal operation of the 144 RECORD button or other 144 controls.

Fig. 5-7A

444 To Paper Tape Punch



Sequence:

1. 444 Puts Data on the DX Lines
2. Lowers XCTRL to Indicate Data Valid
3. Punch Loads Data and Lowers REM LED
4. 444 Removes DATA and XCTRL
5. Punch Releases REM LED to Indicate Ready for More Data

		Min.	Max.
t_{DS}	Data to $\overline{\text{XCTRL}}$ Setup	500 nsec	
t_H	Data and $\overline{\text{XCTRL}}$ Hold Time	100 nsec	1 μsec
t_{PW}	$\overline{\text{REM LED}}$ Low Pulse Width	1 μsec	

5-12A. Time Data Load - Block Sync Mode

So far we have indicated that time data can be loaded via the RS232 serial input, the 07HP, byte-serial input and the parallel input modes. In each of these, the external device must keep track of the number of input samples loaded. In this block sync mode, using the parallel input bus, the analyzer counts input word samples. The block sync mode is described below.

A. The standard 444 is designed to accept digital data into its input buffer from an external source in a simple "handshake" mode of operation. The following signals are used in this operation:

1. XD0 through XD11 ..... J101, Pins 6 thru 17
2. $\overline{\text{X IN DATA WRITE PULSE}}$ ... J101, Pin 46
3. X INT AD EN ..... J101, Pin 47
4. $\overline{\text{X BUFF FULL}}$ ..... J102, Pin 33
5. $\overline{\text{X AD READY}}$ ..... J102, Pin 34
6. GROUND ..... J101, Pin 48
7. AVG TRIG OUT (XSTB3)..... J102, Pin 41
8. $\overline{\text{X BLK SYNC}}$ ..... J102, Pin 32
9. DX16 thru DX 19 ..... J101, Pins 42 thru 45
10. $\overline{\text{DX READ}}$ ..... J101, Pin 49

B. The specification for entering data into the 444 will be summarized below.

1. To enable loading of external digital data into the 444, the X INT AD EN signal must be put into the low state.

2. To initiate a block load of 1024 words, without the necessity of an external counter, the X BLK SYNC must be issued. X BLK SYNC must normally be in the high state; when activated, it must go low for at least 2 microsecond. The trailing edge, i.e., the transition from the low to the high state, will clear the 444 input buffer word counter and will force the status signal X BUFF FULL into the high state signifying that the input buffer count is now initialized at zero.

3. X AD READY pulses, minimum width equal to 1 microsecond in the low state, can be issued at any rate from dc to 150 kHz; each pulse trailing edge, i.e. low to high transition, will result in the data on the XD0 through XD11 bus to be gated into sequential locations in the input buffer memory. The X IN DATA WRITE PULSE is the acknowledge that the write into the buffer has actually taken place. This pulse is actively low for 1.0 microseconds each time a word is written into the input buffer. X AD READY should not be issued sooner than 0.5 microsecond following the trailing edge, i.e. the low to high transition, of the write acknowledge pulse.

4. When the 1024th X AD READY has been issued, the status signal X BUFF FULL will go low signifying that the input buffer is now full and that new input data will overwrite the oldest data sent in the previous block of 1024 words. Consequently, the X BUFF FULL signal is to be used to inhibit transmission of X AD READY pulses when in the low state.

If the user desires to have the analyzer automatically inhibit further buffer load after the buffer full condition then the STOP ON FULL line should be held low. This will cause all words after 1024 following a block sync pulse to be ignored.

5. The input buffer again becomes available when the 444 has read out its entire content of 1024 words. This is signified by a low to high pulse, AVG TRIG OUT, available at J9, BNC, at the rear panel and at J102, Pin 41. This signal is normally high and goes low for 1/2 microsecond, signifying that the input buffer has been emptied and is again available for another block of 1024 words.

6. The external device can now issue another XBLK SYNC pulse which will cause the signal X BUFF FULL to go high. Loading of data can now proceed starting with Step 3.

7. If data is being averaged, each block of 1024 words loaded into the input buffer will result in one additional average. If averaging is to halt after "N" averages, as preset by the NUMBER-N control, then no additional blocks of 1024 words should be loaded into the input buffer. The external device can monitor the number of averages completed by examining the word on the DX bus that has a tag of 13 (AVG STATUS). To determine when to stop loading because the averager has reached N, the N≥ bit is to be examined during the DX READ interval. This bit is low for the number of current averages less than N. When the number of averages ≥ N the bit goes high. The external device should inhibit further input loads until another average is to be initiated. Note that this bit transition will occur sometime after the 1024 word block was entered into the input buffer.

8. Data is frozen in the input buffer whenever the 444 is in HOLD or whenever X INT AD EN is low and X AD READY remains continuously high. To revert to internal data loading mode, it is essential that the X INT AD EN be released (floating) or brought to a logic high level (+3 to +5 volts).

5-13A. Summary

We have reviewed in some detail numerous ways of interfacing the Model 444 Mini-Ubiquitous® Analyzer to other units. The discussion has assumed that the Model 444 is equipped with the -07 (RS232) and the -07 HP (byte serial) options. We have discussed the following:

A. Bi-directional Interfaces

There were three general purpose bi-directional interfaces to the Model 444; these are the bit serial (RS232 interface), the byte serial (-07 HP), and the parallel interface (standard). Some of the characteristics of these are the following:

1. RS232, Type D, half duplex (07 Option) - This interface permits bi-directional communication to an external device at baud rates adjustable from 110 to 9600 baud. ASCII format is used. One connector is used for both communication to and from the analyzer.

2. Byte Serial (07 HP Option) - This bi-directional interface uses ASCII format and permits interface to both the HP9800 series of calculators and HP computers. For

communication with HP computers, it is necessary to use their byte interface card.

3. Parallel - The parallel interface permits more rapid communication in bi-directional modes with the analyzer. A 20-bit wide bus is used and the format is binary coded similar to the format used internal to the analyzer. Two connectors are used for this interface.

B. Dedicated Interfaces

Dedicated interfaces were defined as those interfaces which require initiation by means of a button on the analyzer or analyzer peripheral.

1. RS232 Output (07 Option) - In this interface, the analyzer will feed data to the external device when the front panel STORE CRT button is depressed. The format is the same as the RS232 output format, namely ASCII.

2. Paper Tape Reader - The analyzer will read data from a paper tape reader and start the read operation when the STORE CRT button is depressed.

3. Paper Tape Punch - If data from the analyzer is to be recorded on a paper tape punch, the STORE CRT button, when pressed, will start transfer of data from the analyzer to the punch.

4. Tektronix 4662 Digital Plotter (07 Option) - This plotter uses the RS232 port and will plot what is seen on the CRT display of the analyzer whenever the STORE CRT button is depressed.

5. The Model 144 Tape Recorder - The 144 tape recorder uses the parallel output from the analyzer. Internal settings of the analyzer permit a record operation to be started whenever the STORE CRT button is depressed.

APPENDIX TO SECTION V-A

Pin Connectors

This section provides pin connections and coded format information for interfacing to the Model 444A.

J101 50 Pin Connector

Pin	Mnemonic	Explanation
1	XDS0	
2	XDS1	
3	XDS2	Used for Test Purpose
4	XDS3	
5	XDSEL	
6-25	XD0-XD19	External Data to Analyzer
26-45	DX0-DX19	Data from 444 to External Device
46	$\overline{\text{X IN DATA WRT PULSE}}$	Acknowledge Signal for Input Buffer Load
47	X INT AD EN	Controls Source of Data into Input Buffer High = Internal AD Converter Low = External Data DX Bus
48	GRD	
49	$\overline{\text{DX READ}}$	Negative 2 Usec Pulse Indicates 444 Output Data Stable on DX Bus
50	D BUS EN	Tristate for DX0 through DX15

J102 50 Pin Connector

Pin	Mnemonic	Explanation
1	$\overline{\text{X 2MS CLK}}$	Used for Test Purposes
2	$\overline{\text{XLD PCINH}}$	
3	$\overline{\text{X FLG0}}$	Holding Line at Low Level Permits Remote Control of Upper Front Panel
4	$\overline{\text{X FLG1}}$	Holding Line at Low Level Permits Control of Lower Front Panel
5	$\overline{\text{X FLG2}}$	When Low Inhibits Slew Rate Control on XY Analog Plotter Outputs. Data Emerges at Uniform Rate
6	$\overline{\text{X FLG3}}$	When Low Reads Out Data Starting with Cell 41 Used for Range Translator Offset
7	$\overline{\text{X FLG4}}$	Used to Signal Analyzer Data Available on Input Bus
8	$\overline{\text{X HALT}}$	Used for Test Purposes
9	$\overline{\text{X PADV EN}}$	When Low Inhibits All 444 Logic Steps and Stalls System to Permit Data to be Absorbed by External Device
10	$\overline{\text{X PADV}}$	Used for Test Purposes
11	$\overline{\text{LOAD PCX}}$	
12	Z AXIS ON	
13	X AGV SWP	High While Data is on Display
14	$\overline{\text{XLD PC}}$	Used for Test Purposes

J102 50 Pin Connector

Pin	Mnemonic	Explanation
15	XLD PC SYN	Used for Test Purposes
16-25	PCOX-PC9X	
26	$\overline{\text{XSTOP}}$	External Averager Stop
27	$\overline{\text{XCONT}}$	External Averager Continue
28	$\overline{\text{XRESET}}$	External System Reset
29	$\overline{\text{XSTART}}$	External Averager Start
30	$\overline{\text{XHOLD/REL}}$	External Hold/Release Input
31	$\overline{\text{XARM}}$	External Arm Input
32	$\overline{\text{XBLOCK SYNC}}$	Resets Input Buffer Counters
33	$\overline{\text{XBUFF}}$	Status of Input Buffer Low When Buffer Full
34	$\overline{\text{XAD READY}}$	Pulse Input for Loading Input Buffer
35	PC10X	Used for Test Purposes
36	$\overline{\text{STOP ON FULL}}$	Low State Inhibits Input Buffer Load After Buffer Full
37	XSTBO	
38	XSTB1	
39	XSTB2	
40	XPADV EN SYNC	When Set in Low State Halts System
41	XSTB3	
42	PCBX	Used for Test Purposes
43	$\overline{\text{X RTC INH}}$	Inhibits Display When Low
44	GRD	

J102 50 Pin Connector

Pin	Mnemonic	Explanation
45	$\overline{\text{SMOOTHING INHIB}}$	A Low Inhibits Smoothing on Display
46	$\overline{\text{XCTRL}}$	High to Low Transition Activates Peripheral Devices When STORE CRT Button Depressed
47	$\overline{\text{AVG IN PROC}}$	Indicates Averager Is On
48	REM LED	High to Low Transition from Peripheral Device to 444 to Acknowledge Acceptance of Data and Used to Reset $\overline{\text{XCTRL}}$
49	$\overline{\text{XSTOR CRT}}$	External STORE CRT
50	$\overline{\text{XA}\rightarrow\text{B}}$	External Transfer A→B

RS232C Connector J103

Pin	Mnemonic	Explanation
1	FRAME GRD	Frame (Shield) Ground
2	TRANSMIT DATA	Serial Data From 444
3	RECEIVE DATA	Serial Data Into 444
4	REQUEST TO SEND	Signal From External Device to 444 Requesting Access
5	CLEAR TO SEND	Signal From 444 to External Device Acknowledging a Request to Send
6	DATA SET READY	Not Used-Line Active
7	SIGNAL GRD	
8	CARRIER DETECT	Not Used-Line Active

RS232C Connector J103

Pin	Mnemonic	Explanation
9-10	SPARE	
11	SEC XMIT DATA	Not Used
12	SEC RECEIVE DATA	Not Used
13-16	SPARE	
17	CURRENT LOOP TRANSMITTER	Not Used
18-19	SPARE	
20	DATA TERMINAL READY	Not Used
21-22	SPARE	
23	CURRENT LOOP RECEIVER	Not Used
24	CURRENT LOOP TRANSMITTER	Not Used
25	CURRENT LOOP RECEIVER	Not Used

DX BUS ASSIGNMENT DURING DX READ TIME

0	1	2	3	4	5	6	7	DX 8	9	10	11	12	13	14	15	16	17	18	19	DX 16–19 DEC.	COMMENT
RESOLUTION 0	1	DISPLAY 0	1	2	3	FREQ	AMP	PLOTTER 0	1	AVG MODE 0	1	NUMBER–N 0	1	2	3	0	0	0	0	0	SENSE 0 (UPPER PANEL)
SENSITIVITY 0	1	2	FREQUENCY RANGE 0	1	2	3	4	TRIGGER LEVEL 0	1	2	INPUT 0	1	$\overline{\text{EXT}}$ SAMP	WEIGHTING 0	1	0	0	0	1	1	SENSE 1 (LOWER PANEL)
CURSOR TYPE 0	1	CURSOR MOVE 0	1	FREQ READ	ANNOTATION MODE 0	1	DISPLAY GAIN 0	1	REFERENCE 0	1	UNITS 0	1	STORE CRT	STORE MODE 0	1	0	0	1	0	2	SENSE 2
INPUT WEIGHTING 0	1	AVG IN PROC.		AMPL/OVERLOAD 0	1	2	FREQ EXP 0	1	START	STOP	CONT	TRANS A→B	CAP.	HOLD	ARM	0	0	1	1	3	SENSE 3
CHARACTERISTIC SIGN MSB (2'S COMPLEMENT) LSB								MANTISSA SIGN MSB (2'S COMPLEMENT) LSB								0	1	0	0	4	SPECTRUM OUTPUT (FLOATING POINT)
TIME DATA SIGN MSB (2'S COMPLEMENT) LSB																0	1	0	1	5	TIME DATA
REAL/IMAGINARY DATA SIGN MSB (2'S COMPLEMENT) LSB																0	1	1	0	6	REAL/IMAG DATA
RESOLUTION 0	1	DISPLAY 0	1	2	3	FREQ	AMP	PLOTTER 0	1	LAST POINT						0	1	1	1	7	PLOT POINT IDENTITY
X $\frac{10000}{\text{BCD}}$				X $\frac{1000}{\text{BCD}}$				X $\frac{100}{\text{BCD}}$				X $\frac{10}{\text{BCD}}$				1	0	0	0	8	EXPANDER ORIGIN
CHARACTERISTIC SIGN MSB (2'S COMPLEMENT) LSB								MANTISSA MSB LSB								1	0	0	1	9	REFERENCE VOLTAGE
0=GA. 1=ATT.		NUMBER OF GAIN/ATTEN STEPS														1	0	1	0	10	DISPLAY GAIN
																1	0	1	1	11	SPARE
	CURSOR LOCATION MSB LSB															1	1	0	0	12	CURSOR LOCATION
MSB NUMBER OF AVERAGES COMPLETED LSB								≧N								1	1	0	1	13	AVG. STATUS
UNDEFINED																1	1	1	0	14	POSITIVE ACKNOWLEDGE
UNDEFINED																1	1	1	1	15	NEGATIVE ACKNOWLEDGE

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XD BUS ASSIGNMENTS FOR REMOTE INPUT REQUESTS

0	1	2	3	4	5	6	7	XD 8	9	10	11	12	13	14	15	16	17	18	19	XD 16–19 DEC.	
RESOLUTION 0	1	DISPLAY 0	1	2	3	FREQ	AMP	PLOTTER 0	1	MODE 0	1	NUMBER–N 0	1	2	3	0	0	0	0	0	CONTROL 0 (UPPER PANEL)
SENSITIVITY 0	1	2	FREQUENCY RANGE 0	1	2	3	4	TRIGGER LEVEL 0	1	2	INPUT 0	1	$\overline{\text{EXT}}$ $\overline{\text{SAMP}}$	WEIGHTING 0	1	0	0	0	1	1	CONTROL 1 (LOWER PANEL)
CURSOR TYPE 0	1		FREQ READ	ANNOTATION MODE 0	1			REFERENCE 0	1	UNITS 0	1	STORE CRT		STORE MODE 0	1	0	0	1	0	2	CONTROL 2 (UPPER PANEL)
INPUT WEIGHTING 0	1					FREQ. EXP 0	1	START	STOP	CONT	TRANS A→B			COMP HOLD	ARM	0	0	1	1	3	CONTROL 3 (MOMENTARIES)
CHARACTERISTIC SIGN	MSB	(2'sCOMPLEMENT)	LSB	SIGN	MSB	MANTISSA (2'sCOMPLEMENT)	LSB									0	1	0	0	4	SPECTRUM TO AVG
SIGN	MSB	TIME DATA 2's COMPLEMENT	LSB													0	1	0	1	5	TIME DATA
MSB	$\overline{\text{ASCII DATA}}$	LSB														0	1	1	0	6	8 BIT DATA TO 444
																0	1	1	1	7	8 BIT DATA FROM 444 HANDSHAKE
X 10000 BCD				X 1000 BCD				X 100 BCD				X 10 BCD				1	0	0	0	8	ORIGIN FOR EXPANDER
CHARACTERISTIC SIGN	MSB	(2'sCOMPLEMENT)	LSB	MSB	MANTISSA	LSB										1	0	0	1	9	REFERENCE VOLTAGE
0=GA 1=ATT		NUMBER OF GAIN/ATTN STEPS														1	0	1	0	10	DISPLAY GAIN
																1	0	1	1	11	SPARE
	CURSOR LOCATION MSB	LSB														1	1	0	0	12	CURSOR LOCATION
NUMBER OF AVERAGES COMPLETED MSB	LSB															1	1	0	1	13	NUMBER OF AVERAGES
ASCII DATA MSB	LSB															1	1	1	0	14	8 BIT DATA TO 444
																1	1	1	1	15	8 BIT DATA FROM 444 HANDSHAKE

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E R R A T A

The range expander origin frequency cannot be remotely controlled. The purpose of an origin frequency input on the XD bus is to permit a user to store expanded data in an external device and playback the data for display. By inputting the stored origin frequency on the XD bus, the display will read properly.

APPENDIX TO SECTION V-A

Code Format for DX and XD Buses

Field Title	Code			
1. Resolution	$\underline{R_0}$	$\underline{R_1}$		
400-Line	0	0		
1/3-Octave	1	0		
1/1-Octave	1	1		
2. Display	$\underline{D_0}$	$\underline{D_1}$	$\underline{D_2}$	$\underline{D_3}$
Time	0	0	0	0
Inst	0	0	0	1
A	0	0	1	0
B	0	0	1	1
Inst and A	0	1	0	0
Inst and B	0	1	0	1
A and B	0	1	1	0
A + B	1	0	0	0
A - B	1	0	0	1
B - A	1	0	1	0
A/B	1	1	0	0
B/A	1	1	0	1
3. Frequency Scale (FREQ)	FREQ			
Linear	0			
Logarithmic	1			
4. Amplitude Scale (AMP)	AMP			
Linear	0			
Logarithmic	1			
5. Plotter	$\underline{PL_0}$	$\underline{PL_1}$		
Origin	0	0		
Full Scale	0	1		
At CURS	1	0		
Start Plot	1	1		

Code Format for DX and XD Buses

Field Title	Code			
6. Avg. Mode	$\underline{AV}_0$	$\underline{AV}_1$		
Sum	0	0		
Diff	0	1		
Expon	1	0		
Peak	1	1		
7. Number - N	$\underline{N}_0$	$\underline{N}_1$	$\underline{N}_2$	$\underline{N}_3$
1	0	0	0	0
2	0	0	0	1
4	0	0	1	0
8	0	0	1	1
16	0	1	0	0
32	0	1	0	1
64	0	1	1	0
128	0	1	1	1
256	1	0	0	0
512	1	0	0	1
CONT	1	0	1	0
8. Sensitivity	$\underline{S}_0$	$\underline{S}_1$	$\underline{S}_2$	
100 mv	0	0	0	
200 mv	0	0	1	
500 mv	0	1	0	
1 V	0	1	1	
2 V	1	0	0	
5 V	1	0	1	
10 V	1	1	0	

Code Format for DX and XD Buses

Field Title	Code				
9. Frequency Range (Hz)	$\underline{F}_0$	$\underline{F}_1$	$\underline{F}_2$	$\underline{F}_3$	$\underline{F}_4$
1	0	0	0	0	0
2	0	0	0	0	1
5	0	0	0	1	0
10	0	0	1	0	0
20	0	0	1	0	1
50	0	0	1	1	0
100	0	1	0	0	0
200	0	1	0	0	1
500	0	1	0	1	0
1000	0	1	1	0	0
2000	0	1	1	0	1
5000	0	1	1	1	0
10,000	1	0	0	0	0
20,000	1	0	0	0	1
50,000	1	0	0	1	0
100,000	1	0	1	0	0

10. Trigger Level	$\underline{TL}_0$	$\underline{TL}_1$	$\underline{TL}_2$
+ 1/2	0	0	0
+ 1/4	0	0	1
+ 1/8	0	1	0
+ 1/16	0	1	1
- 1/16	1	1	1
- 1/8	1	1	0
- 1/4	1	0	1
- 1/2	1	0	0

11. Input	$\underline{I}_0$	$\underline{I}_1$
DC	0	0
AC	0	1
Test	1	1

Code Format for DX and XD Buses

Field Title		Code		
12.	EXT SAMPLING	$\underline{X}_0$		
	Freq	1		
	Orders	0		
13.	Weighting	$\underline{W}_0$	$\underline{W}_1$	
	Flat	0	0	
	Hanning	0	1	
	Auto	1	1	
14.	Cursor	$\underline{C}_0$	$\underline{C}_1$	
	Harmonic	1	1	
	Single	1	0	
	Off	0	0	
15.	Cursor Move	$\underline{CM}_0$	$\underline{CM}_1$	
	Left	1	0	
	Right	0	1	
16.	Frequency Reading	$\underline{FR}_0$		
	Hz	0		
	CPM	1		
17.	Annotation	$\underline{A}_0$	$\underline{A}_1$	
	Full	1	1	
	Grat	0	1	
	Data Only	0	0	
	No Display	1	0	Remote Control Only

Code Format for DX and XD Buses

Field Title		Code	
18.	Display Gain	$\underline{D}_0$	$\underline{D}_1$
	Increase	1	0
	Decrease	0	1
19.	Reference	$\underline{R}_0$	$\underline{R}_1$
	1 V	0	0
	R	0	1
	Set R	1	1
20.	Units	$\underline{U}_0$	$\underline{U}_1$
	V_2	0	0
	V^2	0	1
	dB	1	1
21.	Store CRT	$\underline{S}_0$	
	Non-activated	0	See Note at 27.
	Activated	1	
22.	Store Mode	$\underline{SM}_0$	$\underline{SM}_1$
	CRT	0	0
	Plot	0	1
	Aux	1	1
23.	Input Weighting	$\underline{I}_0$	$\underline{I}_1$
	Off	0	0
	A Weighting	0	1
	Spare 1	1	0
	Spare 2	1	1
24.	Avg in Process	$\underline{A}_0$	
	Avg Not in Process	0	
	Avg In Process	1	

Code Format for DX and XD Buses

Field Title	Code		
25. AMPL/Overload	$\underline{A}_0$	$\underline{A}_1$	$\underline{A}_2$
Overload	0	0	0
-6 dB	0	0	1
-12 dB	0	1	0
-18 dB	0	1	1
-24 dB	1	0	0

26. Frequency Expander	$\underline{FE}_0$	$\underline{FE}_1$
Off	1	1
Internal	0	1
External	0	0

27. Start, Stop, Cont, Trans A B

These are momentary switches. The activated state only lasts for a time equal to that required to honor the request.

Active	1

28. Hold	$\underline{H}_0$
Released (Continuous)	0
Hold (No Update or Time Buffer)	1

29. Arm	$\underline{A}_0$
Not Armed	0
Armed	1

Code Format for DX and XD Buses

Field Title	Code

30. Expander

Typical for DX0→DX3, DX4→DX7, DX8→DX11, and DX12→DX15.

	MSB			LSB
0	1	1	1	1
1	1	1	1	0
2	1	1	0	1
3	1	1	0	0
4	1	0	1	1
5	1	0	1	0
6	1	0	0	1
7	1	0	0	0
8	0	1	1	1
9	0	1	1	0

31. Display Gain

		DX0	DX4	DX5	DX6	DX7
Scale	Log 0DB	0	0	0	0	0
	+10DB	0	0	0	0	1
	+20DB	0	0	0	1	0
	+30DB	0	0	0	1	1
	+40DB	0	0	1	0	0
	+50DB	0	0	1	0	1
	-50DB	1	0	1	0	1
	-40DB	1	0	1	0	0
	-30DB	1	0	0	1	1
	-20DB	1	0	0	1	0
	-10DB	1	0	0	0	1

(Con't.)

Code Format for DX and XD Buses

Field Title			Code				
31. Display Gain (Con't.)			DX0	DX4	DX5	DX6	DX7
	Scale	Lin x1	0	0	0	0	0
		x2	0	0	0	0	1
		x4	0	0	0	1	0
		x8	0	0	0	1	1
		x16	0	0	1	0	0
		x32	0	0	1	0	1
		x64	0	0	1	1	0
		x128	0	0	1	1	1
		x256	0	1	0	0	0
		x512	0	1	0	0	1
		÷512	1	1	0	0	1
		÷256	1	1	0	0	0
		÷128	1	0	1	1	1
		÷64	1	0	1	1	0
		÷32	1	0	1	0	1
		÷16	1	0	1	0	0
		÷8	1	0	0	1	0
		÷2	1	0	0	0	1

APPENDIX TO SECTION V-A

Data Formats

The format of some of the "unspecified" DX and XD fields are described in this section.

A. Time Data

The contents of the input time buffer is made available whenever the analyzer display switch is set to TIME. The input buffer is formatted as a two's complement 12-bit binary number, where DX0 = MSB (sign bit). The sign bit is zero for positive numbers and one for negative numbers.

When data is input to the analyzer, the 12-bit two's complement number will be loaded into the time buffer. To ensure equal excursion limits, the input data's most negative legimate number is 100000000001, and the most positive is 011111111111.

B. Spectrum Data

Two types of spectrum data are available, Real/Imaginary and Magnitude data.

1. Real/Imaginary Data

This data is output as a 14-bit, two's complement number in data locations DX0 through DX13. DX14 and 15 are zero. DX0 is a sign bit.

When a code of 6 is detected on the DX16-19 lines,

the first spectrum point corresponds to the real value of the signal in the first resolution element. The next output corresponds to the imaginary component of the signal in the first cell. Alternate real and imaginary outputs follow until 400 resolution cells have been output. This corresponds to 400 real and 400 imaginary words interlaced as R_1 I_1, R_2 I_2, . . . R_{400} I_{400}.

2. Magnitude Data

Magnitude data is represent in power or voltage squared as a floating point number. As such it has both a characteristic and a mantissa.

The characteristic represents the exponent to the base 2 that the number has to be raised. Since the number can be larger than 1 or less than 1, the exponent (characteristic) is signed.

The mantissa is the remainder of the data word which tells what the value of the number is within the 2:1 range determined by the exponent of 2. This number is also signed since the total number can be positive or negative. Thus, the amplitude of the spectrum point can be represented as,

$$A = \pm 2^C \times M$$

where, C is the characteristic (two's complement) and M is the mantissa (two's complement).

The characteristic is represented by 6-bits yielding a 2^{+31} to 2^{-31} range for 2^{C}. M is represented by 8-bits (two's complement form). Several examples are given below.

For A = +8.75

Binary Value	= 1000.11	= 2^{+4} x .100011
Mantissa	= .100011	
Sign of Mantissa	Positive	
M = Total Mantissa	01000110	
C = Characteristic	= +4	= 000100

For A = +3/8

Binary Value (3/8)	= .0110	= 2^{-1} x .110
Mantissa	= .110	
Sign of Mantissa	Positive	
Total Mantissa	01100000	
Characteristic	= -1	= 111111

For A = -3/8

A = -2^{-1} x .110 (See Previous Example)

Sign of Mantissa	Negative
Total Mantissa	= 2's Complement of 01100000 or 10100000
Characteristic	= -1 = 111111

C. Plot Point Identification

A code of 7 in bits DX16 through DX19 at the time the $\overline{\text{DXREAD}}$ is low signifies that a data word has just been entered into the 444 display digital-to-analog converter latch and is

ready for plotting. This flag is useful in controlling the motion of an incremental plotter whose time (or frequency) axis is not being driven by the X output BNC signal of the 444 system.

D. Cursor Location

A code of 12 on the DX16 through DX19 lines during the $\overline{\text{DXREAD}}$ low level indicates that the position of the cursor as a number from 1 to 400 or from 1 to 30 for the 1/3-octave ranges (option) is contained in the bits DX1 through DX9 where DX1 is the most significant bit. DX10 through 15 are zero.

E. Number of Averages Completed

A code of 13 in bits DX16 through DX19 signifies that the bits DX0 through DX9 represent the number of averages as a binary number that have been completed. The number ranges from 0 - 1023. In addition, the bit DX10 indicates that N or more averages have been completed where N is the setting of the spectrum averager number front panel switch. Thus, if 512 averages have been selected, bit DX10 will not become true (1) until 512 or more averages have been completed.

1. Acknowledge Output

A code of 14 in positions DX16 through DX19 during the time that $\overline{\text{DXREAD}}$ is low signifies a positive acknowledge

for data previously input to the 444 via the XD bus. This command indicates that data which was input on the XD has been accepted by the system as bearing a legimate code.

2. Negative Acknowledge Output

This condition is represented by a code of 15 on DX16 through DX19 during the low level condition of the $\overline{\text{DXREAD}}$ and signifies that the input data on the XD bus contained an illegal code. In this case, the 444 analyzer will not accept the data and it is the responsibility of the user to re-enter the correct information with the correct code.

F. External Device Flags

In addition to the DX output and the XD input buses and the $\overline{\text{DXREAD}}$ which are used for two-way communication between the 444 and an external device, there are five special input flag signals that are used in conjunction with these buses. The names and locations of these signals on the rear panel connector have been indicated and their functions are described below.

1. $\overline{\text{XFLG0}}$

When low, the upper panel will be placed into the remote control mode. In this state the front panel settings, that were established by means of the front panel controls, will be retained until updated by external data. When external flag 0

is held low, the front panel controls no longer effect the operation of the system. The loading of front panel control information is via the remote load interfaces described previously.

2. $\overline{\text{XFLG1}}$

When this signal is held low, the lower front panel will be under remote control. In this case, any changes in the lower front panel controls is ineffective and only by means of external remote inputs can the settings be changed.

3. $\overline{\text{XFLG2}}$

When low, commands the 444 to inhibit normal slew rate limiting (time out), used in X-Y plotting mode. Plotters driven at a uniform rate on their time axes require uniformly spaced out put data.

4. $\overline{\text{XFLG3}}$

When low, will force the 444 to analyze, display an output spectrum data starting at the 41st frequency cell, that is, 10% of the applicable frequency range through the 440th cell, or 10% above the upper frequency of the frequency range. This 10% shift is used when the input signal to the 444 is derived from the range translator.

5. $\overline{\text{XFLG4}}$

Used in communications on the parallel bus and indicates to the analyzer that data is stable on the input lines. This has been described previously in the interfacing section.

Signals are entered via connector J102, pins 3, 4, 5, 6, and 7 respectively, for external flags 0-4.

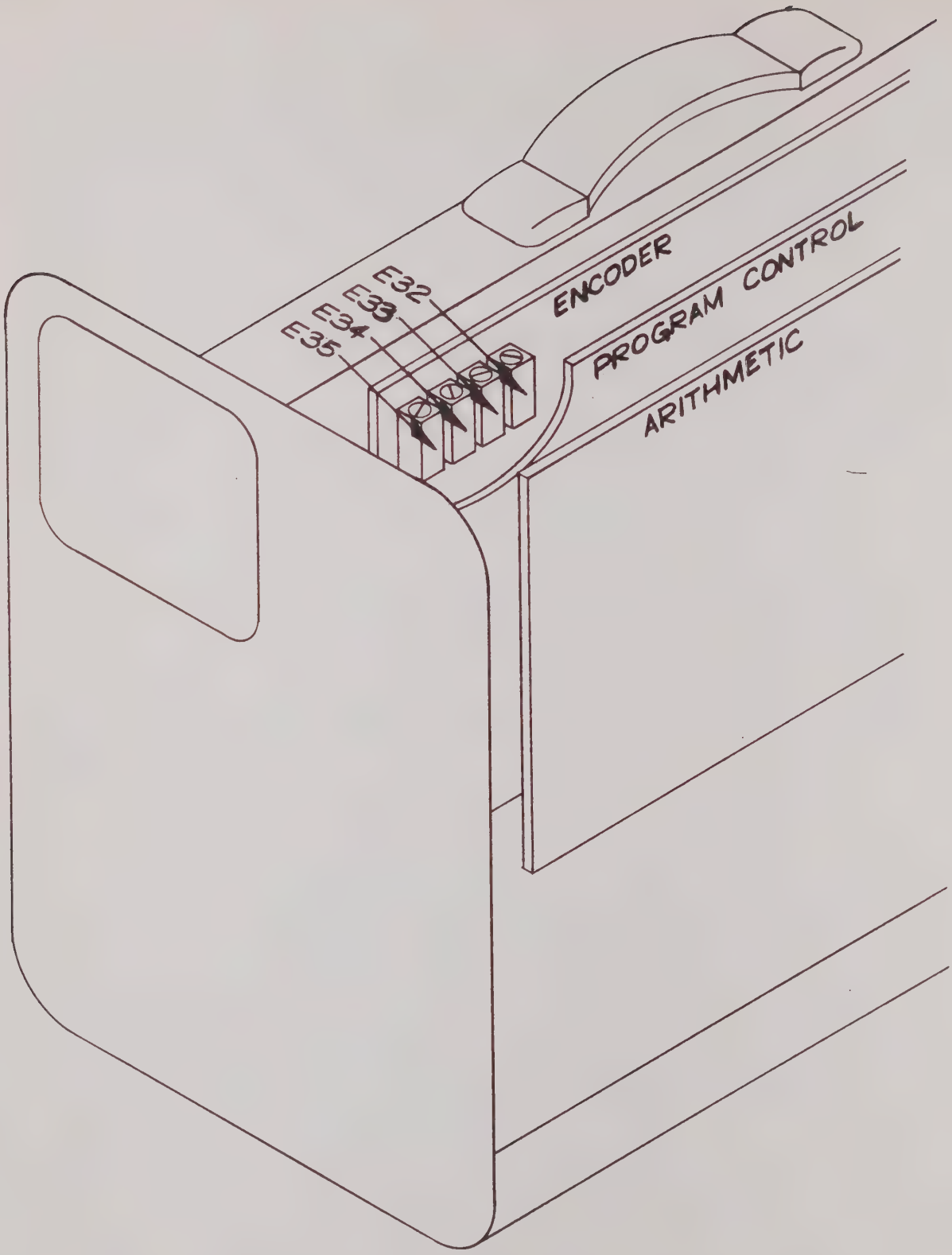


FIGURE 5-8A. LOCATION OF INTERNAL ENCODER BOARD SWITCHES

APPENDIX TO SECTION V-A

Dedicated Digital Device Switch (See Figure 5-5A)

E32 (Encoder Board)

		Switch E32 Setting	
		Fast Peak Averager*	Normal Peak Averager
1.	144 Digital Cartridge Recorder	0	8
2.	Start Paper Tape Reader	1	9
3.	RS232 Output		
	a. Sense and Real/ Imaginary Dump	2	A
	b. Sense and Spectrum or Time	4	C
	c. Sense, Real/ Imaginary Dump and Spectrum or Time	6	E
4.	Paper Tape Punch		
	a. Sense and Real/ Imaginary Dump	3	B
	b. Sense and Spectrum or Time	5	D
	c. Sense, Real/ Imaginary Dump and Spectrum or Time	7	F

*Note: In fast peak averager mode, averager is updated at the processing rate rather than the 50 percent redundancy rate normally used.

APPENDIX TO SECTION V-A

RS232 Output Option Switch

E33 (On Encoder Unit)

RS232 Opt. Switch Position	CR/LF	Baud Rate
0	No	110
1	Yes	110
2	No	150
3	Yes	150
4	No	300
5	Yes	300
6	No	600
7	Yes	600
8	No	1200
9	Yes	1200
A	No	2400
B	Yes	2400
C	No	4800
D	Yes	4800
E	No	9600
F	Yes	9600

E34 Request-to-Send Protocol

E34 (On Encoder Unit)

0 - Analyzer Ignores Request-to-Send Inputs

1 - Analyzer Honors Request-to-Send Inputs

E35 For Factory Test Purposes Only

E35 (On Encoder Unit)

B - Normal Position

SECTION VI

MODEL 444 BLOCK DIAGRAM DESCRIPTION

6-1. Scope of This Section

This section will present a block diagram description of the 444 system and will provide a breakdown of each block with regard to its function and physical board location.

6-2. Organization of the 444

The 444 is organized so that the input plug-in unit performs all the necessary analog signal conditioning and digitizing of the input signal prior to actual system processing. Six small printed circuit boards comprise the basic plug-in unit and these boards will be described in further detail below. The -20 plug-in makes use of the same six boards, but has an additional three boards which are described in Section VIII of the manual. These boards contain the expander circuits.

Digital signal processing, display control, and front panel interfacing is performed on three large wire-wrap boards located in the mainframe of the 444. The digital signal processing section accepts its input data from the plug-in unit's analog-to-digital converter and provides two output buses, i.e., the horizontal and vertical buses, as well as Z-axis and mode control signals to the system's display board.

The function of the system display is to convert the digital bus signals into corresponding analog signals to drive the corresponding deflection plates of the system display CRT. In addition, the display system, under the processor's control will gate the display on or off, and will scale deflection voltages according to mode commands received. The display system also provides the system's pen output, and buffered horizontal and vertical outputs.

6-3. Basic Block Diagram Description (Figure 6-1)

Data applied to the system's input is attenuated under operator control, lowpass filtered so that its frequency response

cuts off sharply at the band edge selected by the FREQUENCY RANGE control, and then digitized in the analog-to-digital converter. Each digitized input sample is placed into a successive location in the 1024 word input buffer. Note that unless the system is placed into a HOLD mode, or sampling is interrupted, this process is a continuous one. Consequently, every new input sample will overwrite, or replace, the input sample that was collected 1024 sampling intervals earlier. Input data collection is virtually independent of system control.

A block indicated in Figure 6-1 as MULTIPLEXER shows four inputs and one output. One of these inputs is the data output from the input buffer. Another input is the output bus from the system's microprocessor. The two other inputs are provided by the output from the system's active memory bank and a remote source, respectively. Although shown as a single input line, it is important to remember that each of the lines represent one or more buses.

The block indicated as MICROPROCESSOR actually consists of a number of separate block functions, which will be described in greater detail. At this point, however, it is important to realize that the MICROPROCESSOR is the controlling element of the 444 system. The MICROPROCESSOR is programmed to sequence through a predetermined number of steps, at each step performing either a group of control functions, arithmetic computations, or data manipulations, or combinations of these operations.

The MICROPROCESSOR determines which input bus to the MULTIPLEXER will appear at its output and whether that bus will be entered into one of its random memory locations or undergo logic or arithmetic manipulation with any of the MICROPROCESSOR'S internal buses.

The sequence of steps through which the MICROPROCESSOR progresses is dictated by a program stored within the MICROPROCESSOR itself. After the MICROPROCESSOR has sequenced through the required number of steps, the original data block of 1024 data samples will have undergone transformation from the time to the frequency domain.

Further data manipulation by the MICROPROCESSOR averages spectra and stores the averaged spectrum in one of its internal active memory banks.

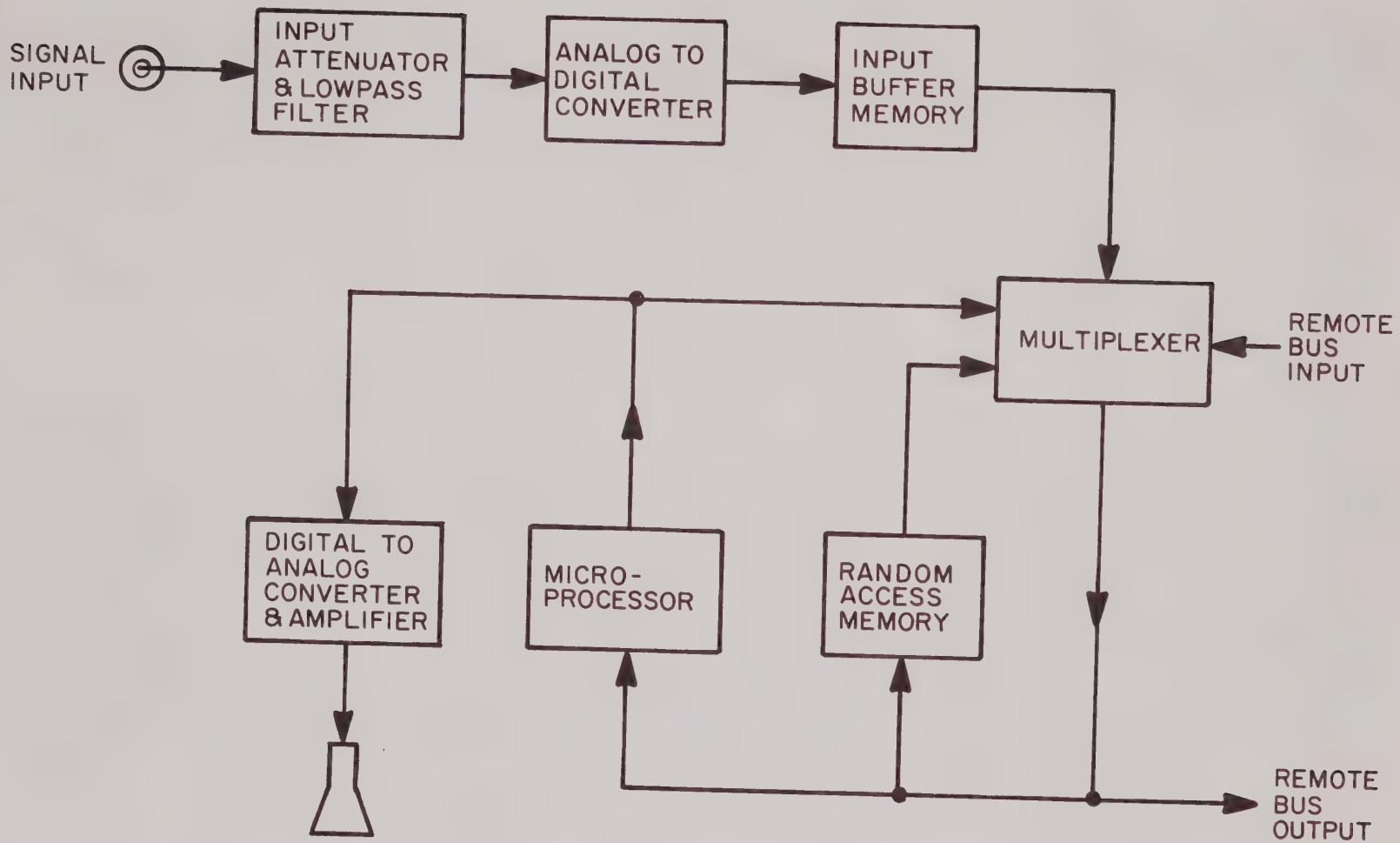


FIGURE 6-1. BASIC BLOCK DIAGRAM

The MICROPROCESSOR interrupts processing on a periodic basis to refresh the display with the most recent data to be presented, as well as to redraw the graticule and various annotation data.

Almost all front panel controls are read by the MICROPROCESSOR and echoed back to the appropriate point in the system where they are to be used.

Input and output interface control is exercised by the MICROPROCESSOR and communicated via the input and output buses available at the rear panel connectors of the unit.

6-4. Plug-In Board Description and System Block Diagram (Figure 6-2)

A. The following discussion will describe the -10 plug-in boards in detail and their function within the system. (The numbers correspond to the numbers in Figure 6-2.)

1. INPUT ATTENUATOR - The inputs to this board are the INPUT SIGNAL from the front panel INPUT SIGNAL BNC or the TEST SIGNAL generated on the SAMPLING CONTROL board. Under front panel control, one of these signals is selected and applied to a compensated step attenuator network, controlled by SENSITIVITY control on the front panel. The output of this network is then buffered and amplified.

The INPUT ATTENUATOR board also contains the shaping circuit required for the ORDER CONTROL SAMPLING INPUT signal so that a wide range of input levels and waveforms can be accommodated for external sampling.

2 and 3. FILTER NO. 1 - FILTER NO. 2 - These two boards accept the output signal from the INPUT ATTENUATOR and pass the signal through a buffer stage, a 10-stage 7-pole, elliptic, active filter, and a final gain and offset stage. All passive components used in these stages to determine frequency characteristics of the filter, are controlled by the FREQUENCY RANGE controls, or when remotely controlled by external commands.

4. A/D CONVERTER - This board receives the lowpass filtered signal from FILTER 2 board, samples and holds the signal at the sampling clock rate, performs a successive approximation of the sampled signal, and provides a parallel 12-bit digital

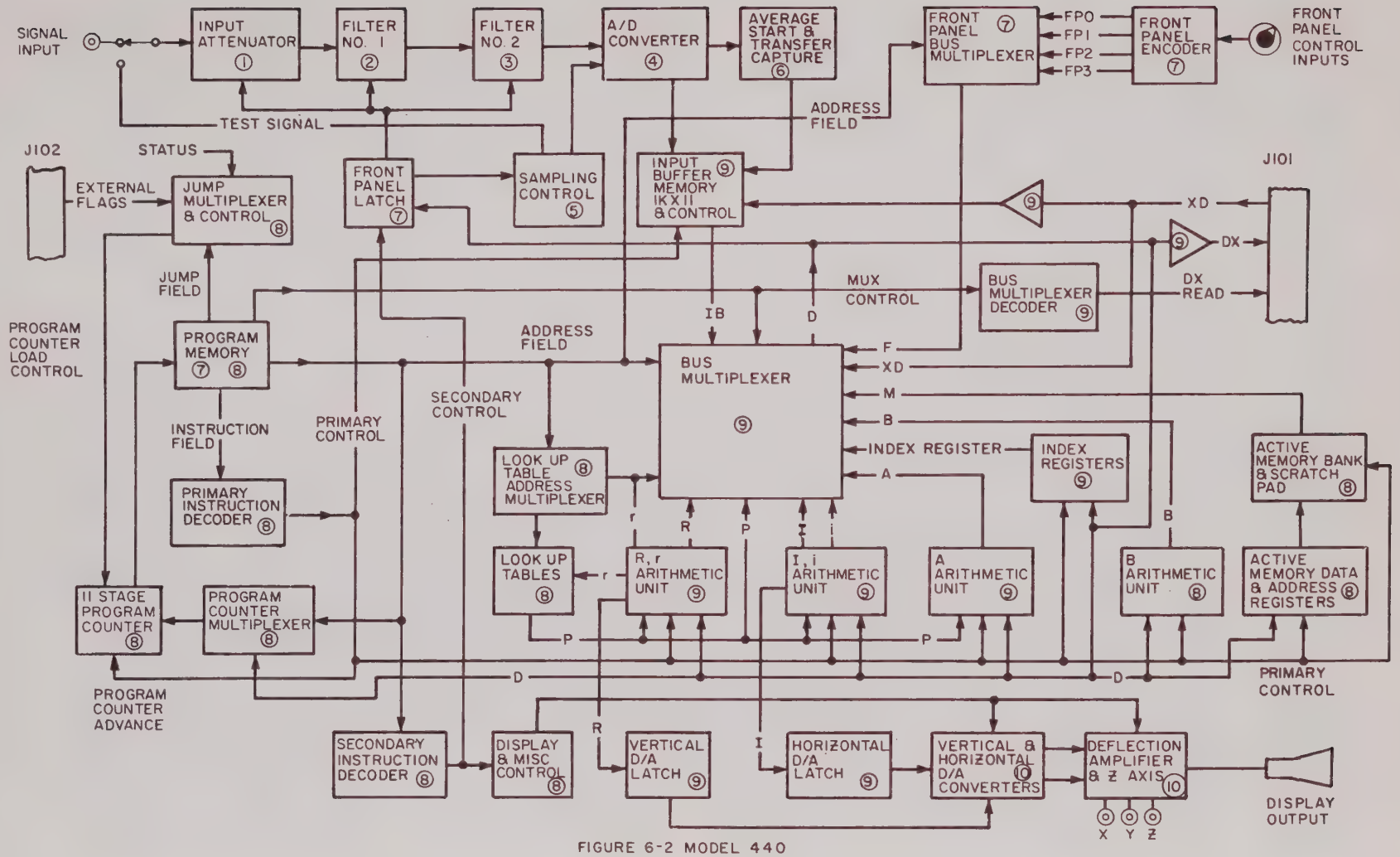


FIGURE 6-2 MODEL 440
SYSTEM BLOCK DIAGRAM

word at the end of each analog-to-digital conversion cycle. This bus is tri-stated with the external input bus and directly applied to the input buffer.

5. SAMPLING CONTROL - This board contains the crystal oscillator and countdown circuits which generate the internal sampling frequency pulses required for the various frequency ranges selectable at the front panel. The system Test Signal is also generated on this board. This signal has a fundamental frequency equal to 64 percent of the selected FREQUENCY RANGE and will appear at 64 percent of the sweep when the internal sampling mode of operation is selected. A two millisecond clock signal is also provided by this board to the system which is subsequently counted down to the real time clock frequency of the 444 system.

6. AVERAGER START and TRANSIENT CAPTURE - The functions of this board are to generate gated end-of-conversion pulses to the write control portion of the system, to generate averager enable flags based on the input data blocks, and to regulate the HOLD operation through either manual control, or signal threshold crossing when the system has been placed in the ARMED position.

Averager start pulses are generated when either a full block of 1024 words have been entered into the input buffer memory in the external block sync mode, or whenever 512 words have been collected in the continuous sampling mode. The 512 word, 50 percent redundancy mode, permits faster averaging at the expense of some data overlap.

Digital data processed by the system is derived from either an external source or an internal source. Gated end-of-conversion pulses are derived from the delayed internal or external sampling clock. These pulses may be gated off in either of these modes whenever a full block of 1024 words are collected, if the control signal $\overline{\text{STOP ON FULL}}$ is activated in the low state. End-of-conversion pulses are also gated off whenever the HOLD is activated or whenever the system has been ARMED and the signal threshold commanded by the TRIG LEVEL control is exceeded.

The block sync pulses accepted by this board and the status flip-flop $\overline{\text{BUFFER}}$ FULL serve to delineate blocks of 1024 words when used in conjunction with an external data source and external end-of-conversion pulses.

Other output signals from this board include the drive signals for the front panel: ARMED, HOLDING, OVERLOAD, and AMPLITUDE indicators.

6-5. Mainframe Board Description and System Block Diagram (Figure 6-2)

A. The following discussion will describe the functions and interactions of the three large system boards with respect to the presentation of the block diagram in Figure 6-2.

7. ENCODER - This board contains the interface between the front panel and the system Microprocessor. Front panel switch contacts are encoded and assembled into four processor words. At any point in the program, a secondary instruction may be issued which will select one of these four data words and permit it to appear at the output of the Bus Multiplexer. In this manner, the Microprocessor is able to read the entire front panel status in a sequence of four secondary instructions. The meaning of the term "secondary instruction" will be explained below.

The Microprocessor echoes front panel settings back to the corresponding control circuits, where necessary, by placing the matching data word on the common "D" bus through one of the other inputs to the Bus Multiplexer. Again, under secondary instruction control, the "D" bus is clocked into the front panel latch which in turn exercises control over such operations as INPUT SENSITIVITY, TEST/INPUT SIGNAL, FREQUENCY RANGE, and FREQ/ORDERS. If the 444 is commanded to control the lower front panel from a remote source, the "D" bus that is returned by the Microprocessor into the front panel latch will reflect a command that was applied by the remote source on the external input bus, and will not be an echo of the corresponding front panel bus.

The ENCODER also includes special debouncing and synchronizing circuits for front panel switch contacts, where required. In addition, the system's Program Memory is located on the ENCODER and this block will be described in conjunction with the PROGRAM CONTROL board below.

8. PROGRAM CONTROL - This PROGRAM CONTROL board includes the Program Counter, Primary and Secondary Instruction Decoders, Jump Multiplexer, Random Access Memory Banks and Data Registers, Look-Up Tables, and the "B" Arithmetic Unit. These units will now be explained:

a. Program Counter - The Program Counter determines the sequence of instructions that are executed in the system by generating sequential instruction addresses to the Program Memory. The counter can either step by an increment of one, which occurs when no special jump decision is made by the program, or can be loaded with a value determined by the current instruction itself. This value may be either a "literal" value, i.e., one that is directly derived from a portion of the instruction word, or from the system "D" bus. Recall that this is the common output bus from the Bus Multiplexer. The selection of input bus to appear at the output of the multiplexer is, of course, also executed by the current instruction word.

b. Program Memory - The Program Memory consists of groups of ROM's (Read Only Memories) which are addressed by the Program Counter to provide the instruction words that sequence the 444 system through its operations. Each instruction word is broken into eight fields, as follows:

Four fields are used to provide four independent instructions to four groups of arithmetic units within the system.

One field is used to independently address the system's "scratch pad" memory.

One field is coded to activate the jump operation upon detection of a system status assigned to that code.

One field is coded to select one input bus to the Bus Multiplexer to appear at the multiplexer output, i.e., the "D" bus.

The eighth field contains the address to be loaded into the Program Counter upon detection of a jump status condition. If an unconditional "no jump" is commanded, this field is used to address various Look-Up Tables used by the 444 system. If the "no jump" command condition is true, and only a limited portion of this field is needed for a Look-Up Table, then the remaining portion of this field is used as a set of secondary instruction codes.

c. Primary Instruction Decoder - The four fields containing four separate instruction words to the various arithmetic units within the Microprocessor portion of the system are binary coded for maximum efficiency. To translate these coded instruction words into corresponding hardware control signals, the Primary Instruction Decoder is used. Note that the four fields comprise the primary instruction portion of the entire word because these fields are dedicated to arithmetic instruction and multi-control. In contrast, the secondary instruction portion of the entire instruction word is shared with the address function of the same field, and generally yields only a single control function at any given time.

d. Secondary Instruction Decoder - This block of hardware decodes the secondary instruction portion of the address field (the eighth field described above) and generates a unique control function for any given code. As noted above, secondary instructions are inactive if a jump condition is tested or if the full address field is dedicated to a lookup operation.

e. Look-Up Tables - These tables contain all the necessary constants and conversions, e.g., logarithms and anti-logarithms, as well as alpha-numeric coded character images, for reference by the main program.

f. Look-Up Address Multiplexer - The Look-Up Tables may be addressed directly by the address field of the instruction word or by a specific system register output (the "r" bus shown in the block diagram) such as would be required when the address is data dependent. The Look-Up Address Multiplexer selects the appropriate bus and this selection in turn is controlled by the high order bits of the address field.

g. "B" Arithmetic Unit - This arithmetic unit is configured to efficiently implement address manipulation used in the processing algorithms of the Fast Fourier Transform.

h. Display and Miscellaneous Control - This hardware includes all the Microprocessor I/O controls to the Display section of the 444 system, e.g., logarithmic scale, plot mode, intensity axis gate, as well as certain controls used by the Microprocessor itself. The latter includes the acknowledgment of the real time clock, program flags, reset of hardware flags, control of the front panel IN PROCESS indicator, and

loading of the Front Panel Latch. Also included in this block are various controls required for the operation of output devices, such as the Tektronix 613 Storage Oscilloscope. Note that the inputs to this block are the outputs from the Secondary Instruction Decoder.

i. Active Memory, Data and Address Registers - These registers contain the data and the address values to be used in conjunction with a selected memory from the active memory bank. The inputs to both these registers are provided by the system "D" bus.

j. Active Memory Bank and Scratch Pad - The active memory is made up of three memory groups:

(1) Processor Memory
(2) Averager Memories
(3) Display Buffer

The Processor Memory stores the input array of sampled data and successive transformations of this data into an array of frequency elements. The complex spectrum is derived from this memory after the final transformation process.

The Averager Memories store the accumulated values of successive power spectra when the averaging mode is enabled. The method of accumulation is, of course, determined by the front panel SPECTRUM AVERAGE mode controls.

The Display Buffer is used to store the 400 spectral values appearing on a frequency display. Note that time data passes directly from the input buffer to the display and does not get buffered in the Display Buffer. Data stored in the Display Buffer is formatted prior to entry into the buffer.

9. ARITHMETIC UNIT - The ARITHMETIC UNIT board contains a number of different arithmetic units, some of which are internally cross-coupled and all of which are connected to the system "D" bus at their input and contribute to the "D" bus via the Bus Multiplexer at their output. The ARITHMETIC UNIT also includes the Input Buffer Memory and Control, the Vertical and Horizontal D/A Latches, and Index Registers for general control, as well as the Bus Multiplexer. These blocks will be described in the paragraphs that follow:

a. "R,r" Arithmetic Unit - This arithmetic unit contains two extensive registers, corresponding arithmetic logic units, and additional multiplexing and control. It is used, in conjunction with the "I,i" Arithmetic Unit to perform FFT data processing, as well as the bulk of display, averaging, and control processing. This arithmetic unit has direct access to the output of the Look-Up Tables, i.e., the "P" bus, and the output of the "I,i" Arithmetic Unit, as well as the system's common "D" bus.

b. "I,i" Arithmetic Unit - This arithmetic unit is structured identical to the "R,r" Arithmetic Unit and shares the bulk of system processing with that unit. Note that both these arithmetic units are controlled by a common instruction field; however, the resultant decoded instruction to these arithmetic units generally represents two different operations for the two units.

c. "A" Arithmetic Unit - This is an auxiliary arithmetic unit primarily intended for angle accumulation in the FFT algorithm but used in various portions of the program where its use is required.

d. Index Registers - A set of two independent index registers are available for program use as delay or time-out elements. Their carry outputs are capable of being sensed and are generally used in a conditional jump operation.

e. Vertical and Horizontal D/A Latches - Data that is ready for transfer to the Display Subsystem is entered into these latches directly from the outputs of the "R,r" and the "I,i" Arithmetic Units. Loading of these latches is, of course, controlled by the program and occurs only during the display portion of the program.

f. Input Buffer Memory and Control - Data from the A/D Converter, or data from an external source when selected, is entered into a 1024 word buffer memory. Writing into this memory occurs at the data sampling rate and is essentially independent of program control. However, reading of data from this memory is entirely under program control and must be distinct in time from the write operation. Consequently, writing into the memory will be inhibited during a read operation and will be executed immediately thereafter if a write request is present.

As shown on the block diagram, data read from this memory is one of the inputs to the Bus Multiplexer and appears on the "D" bus when selected by the program.

g. Bus Multiplexer - This multiplexer includes every major bus output from an arithmetic or memory unit, as well as front panel multiplexed bus, address-field literal data, and the Look-Up Table "P" bus output. The control of the Bus Multiplexer is derived from a separate field in the instruction word and, although not shown on the block diagram, may be overridden by external select commands.

h. Bus Multiplexer Decoder - Data appearing on the "D" bus also appears on the buffered "DX" bus at the J101 rear panel connector. However, only certain types of data are significant for an external device; consequently, it is necessary to provide a read strobe and an identification code on the bus itself to alert the external device to the type of data currently on the bus. Whenever the 444 provides output data, a restricted code is used to select one of the inputs to the multiplexer. Upon detection of this code, the Bus Multiplexer generates a $\overline{\text{DX READ}}$ strobe, nominally two microseconds in duration during which time data remains stable on the "DX" bus. The coded portion of the "DX" data may be examined during the time $\overline{\text{DX READ}}$ is asserted and the device may either reject or accept the current data frame depending on the detected code.

10. DISPLAY BOARD - The DISPLAY BOARD contains the Vertical and Horizontal Digital-to-Analog Converters and the corresponding low and high voltage Deflection Amplifiers, as well as Z-axis level translators, plot control circuits, coordinate rotation controls, and gain and offset controls.

SECTION VII

USER ADJUSTMENTS

7-1. Scope of This Section

This section of the instruction manual provides the user with the necessary information for adjusting certain system controls without the need to introduce special test equipment. Controls other than those provided for customer use will be included in this section for information only. These controls have been preset at the factory and should not be readjusted without prior consultation with Nicolet's Service Department.

7-2. Input Offset Adjustments

A. AC Coupling:

Set the following switches to their indicated positions:

TEST/AC/DC	to AC
DISPLAY	to TIME
ANNOTATION	to FULL
FREQ/ORDERS	to FREQ
HOLD/REL	to REL
INPUT SIGNAL	to none

The display should consist of a horizontal line aligned with the fifth vertical tic mark. If this line is not on the fifth tic mark, adjust potentiometer R1 (20,000 ohms) on the AD CONVERTER for proper alignment.

B. DC Coupling:

Set the TEST/AC/DC switch to DC. All other settings should remain as in paragraph A. above.

Set INPUT AMPLITUDE control to its maximum clockwise positions, i.e., 100 MV, and ground the INPUT SIGNAL BNC.

Again the display should consist of a single horizontal line at the fifth vertical tic mark. If this is not so, three controls may be adjusted for centering the line.

On the INPUT ATTENUATOR card adjust potentiometer R1 (1000 ohms) and R2 (20,000 ohms) for proper centering of the horizontal line.

If there is insufficient range in this adjustment, potentiometer R15 (20,000 ohms) on FILTER NO. 2 may be adjusted to complete the centering alignment.

7-3. Input Gain Adjustment

Set the following switches to their indicated positions:

TEST/AC/DC	to AC
INPUT AMPLITUDE	to 0 dB (COARSE and FINE)

Apply a sinusoidal INPUT SIGNAL at a frequency of one percent of selected FREQUENCY RANGE and at an amplitude of 280 MV peak to peak (100 MV RMS).

Set the VIEW switch to TIME and verify that the displayed signal is at the threshold of clipping at both top and bottom extremes. If not, adjust potentiometer R2 (2000 ohms) on the A/D Converter until this occurs. If slight clipping is not symmetrical, it may be necessary to readjust the AC offset control outlined in paragraph 7-2, A., above, and then repeat the gain adjustment. After symmetrical clipping is achieved, no further offset adjustment should be made, although exact centering may have been slightly affected in the gain adjustment procedure.

7-4. A/D Converter Adjustments

The following potentiometers on the A/D Converter are used to adjust the relative weights of A/D Converter bits. They are listed below for information only and should not be adjusted without prior consultation with Nicolet Scientific Corporation.

Control	Function
R3	Correct weight for 1/2 MSB
R4	1/4
R5	1/8
R6	1/16
R7	Correct weight for the sum of all succeeding lower bits, equal to 1/32 MSB.

7-5. Display Adjustments

Unless otherwise noted, all display adjustment controls are located on the Display Circuit board. (See Figure 7-1.) Extreme caution should be used when servicing the Model 444 with any of its side panels removed. Lethal voltages exist within this unit. The Display Circuit controls should always be adjusted through the holes provided on the protective plexiglass cover. Removal of this cover with power applied to the unit should be attempted by trained personnel only. All adjustments made by the user are to be made to achieve the optimum result based on the function of that control only. In general, optimum results are observed on a working display with the FULL ANNOTATION on.

1. FOCUS - This control is mounted in a small enclosure on the frame behind the Display Circuit board. This control is adjusted to achieve optimum definition of both horizontal and vertical lines on the display. The control will generally interact with the ASTIGMATISM control and should be adjusted under normal screen intensity setting.

2. INTENSITY - This control is located directly below the FOCUS control. The adjustment may be made to suit the viewer for ambient lighting conditions; however, excessive brightness makes FOCUS adjustment more difficult and may shorten the life of the CRT.

3. R13), ASTIGMATISM - Adjust this control for equal focus of horizontal and vertical lines. Readjust FOCUS if necessary.

4. R14), PATTERN CORRECTION - Adjust this control for minimum bowing of the vertical graticule lines. Check corners

of the graticule for optimum alignment with horizontal graticule lines. This control will generally interact with the ASTIGMATISM control.

5. R4, VERT ROTATE and R10 HORIZ ROTATE - These controls are adjusted to achieve a graticule whose vertical and horizontal lines are perpendicular to each other and parallel to the vertical and horizontal edges of the CRT, respectively. Both controls will generally have to be adjusted simultaneously.

6. R7, VERT HF ADJUST and R1, HORIZ HF ADJUST - These controls affect the high frequency compensation of the two deflection amplifiers. Their effect can best be observed at the graticule corners. Adjust these controls so that at the corners of the graticule the horizontal and vertical lines meet with minimum change in slope and intensity, and with minimum overshoot.

7. R8, Y OFFSET and R2, X OFFSET - These controls may be used to obtain a pattern optimally positioned vertically and horizontally on the CRT. Note that if the VERT. OFFSET or HORIZ. OFFSET controls are subsequently adjusted for minimum offset on Y OUT or X OUT signals, the Y OFFSET or X OFFSET controls may require readjustment for optimum centering on the CRT.

8. R3, HORIZ SPAN; R9 VERT SPAN - These controls are used to control the gain in the horizontal and vertical axis.

9. R12 VERT OFFSET; R6 HORIZ OFFSET - These controls are normally factory preset so that an all zero digital word into the D/A Converters will produce an analog output of zero volts at the X-Y plotter outputs. However, if for any reason the user wishes to readjust these controls to suit his needs, he may do so. It will then be necessary to readjust the X OFFSET or Y OFFSET control for CRT centering since the offset added by the first adjustment is also in the main signal path.

10. R5, X CRT ZERO; R11, Y CRT ZERO - These controls are normally factory preset so that the X and Y outputs to the external display will be at a zero volt reference. However, if for any reason, the user wishes to readjust these controls to suit his needs, he may do so by displaying the outputs on his X-Y oscilloscope and adjusting these controls for optimum centering.

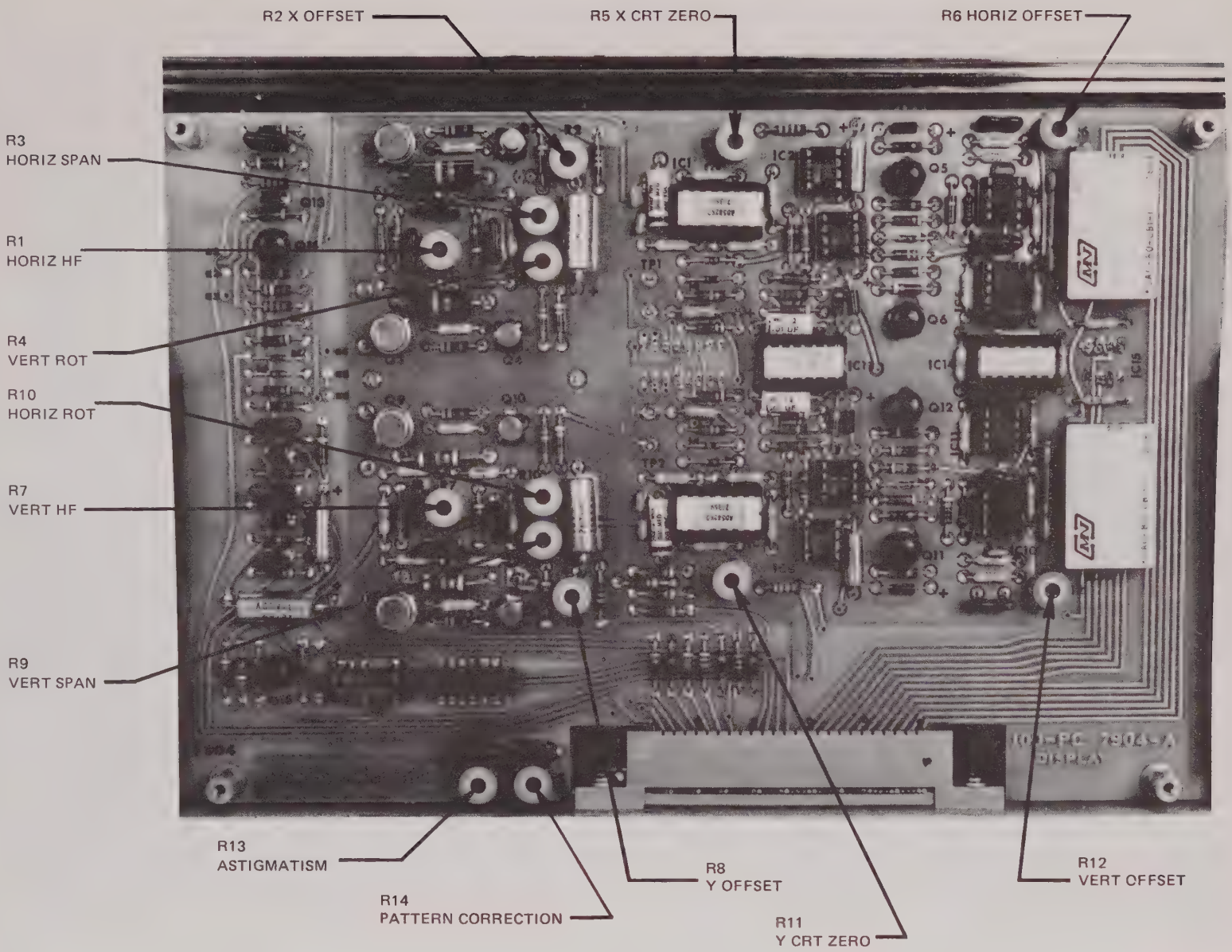


FIGURE 7-1. DISPLAY BOARD ADJUSTMENT LOCATIONS

7-6. Power Supply

A. Description

This power supply convertor employs the switching type inductor storage design. The unit is capable of delivering a regulated +5 volt output and unregulated +20, -20, +40, -40, and +225 volt outputs. The regulated +5 volt supply is adjustable between 4.50 volt to 6.25 volt at the output connector. In addition, the convertor has an inherent self-protecting power-limiting capability.

The unregulated outputs are regulated by the regulator board to provide regulated +15, -15, +30, -30 and +175 volt outputs. In addition, this supply includes a high voltage convertor section which generates the +1500, -1500, and 6.3 volt output for the cathode ray tube power requirements.

All the voltages have a common floating ground at the output of the main power convertor. Table 7-1 summarizes the output voltages and maximum currents from the supply.

Table 7-1. Power Supply Outputs

Voltage (Volts DC)	Maximum Current (Ampere DC)
+5.2	14
+15	1
-15	1
+30	0.1
-30	0.1
+175	0.02
+1500	20 μa
-1500	20 μa
-900	20 μa
6.5 (AC)	0.3 (AC rms)
+38 unregulated	

B. Convertor Block Diagram

Figure 7-2 is a simplified block diagram of the main power convertor. It consists of five major elements.

a. Line EMI Filter, Rectifier and Filter
b. Oscillator
c. Drivers and Switches
d. Transformers, Rectifier, and Filters
e. Feedback Amplifier and Isolator.

C. Theory of Operation

Line voltage is passed through an Electro-Magnetic Interference filter. This is to prevent high frequency noise generated in the convertor from being fed back into the line, and line noises from entering the system through the power supply.

The AC line voltage is then fed to the rectifier circuits. This circuit consists of a voltage doubler and filter for 110V AC input or a full wave rectifier and filter for 220V AC input. This rectified voltage (V+) is the main operating voltage for the convertor, and is between 250V DC and 350V DC.

During initial start-up condition, the oscillator obtains its operation voltage (B+) from V+ through a 5 volt series regulator. Once normal operating conditions are established the oscillator utilizes one of the main transformer outputs. The start-up operating voltage of B+ is 5 volts and the normal operating voltage of B+ is between 8 to 15 volts.

At 5 volts, the oscillator will operate as bistable oscillator with fixed frequency and duty cycle. At voltages above 5 volts, the oscillator will operate as voltage controlled oscillator with fixed "on" cycle. The controlling voltage is the output of the feedback error amplifier. The output of the oscillator is the switching pre-driver for the driver stages.

There are two identical drivers, each driving an independent switching transistor in series with the transformer. During "on" periods, the transformer will have the characteristics of a pure inductor because all the secondary rectifier diodes are reverse biased. The electrical energy is now stored in the transformer as magnetic energy. As soon as the switch is off, the current feeding through the transformer is temporarily cut off.

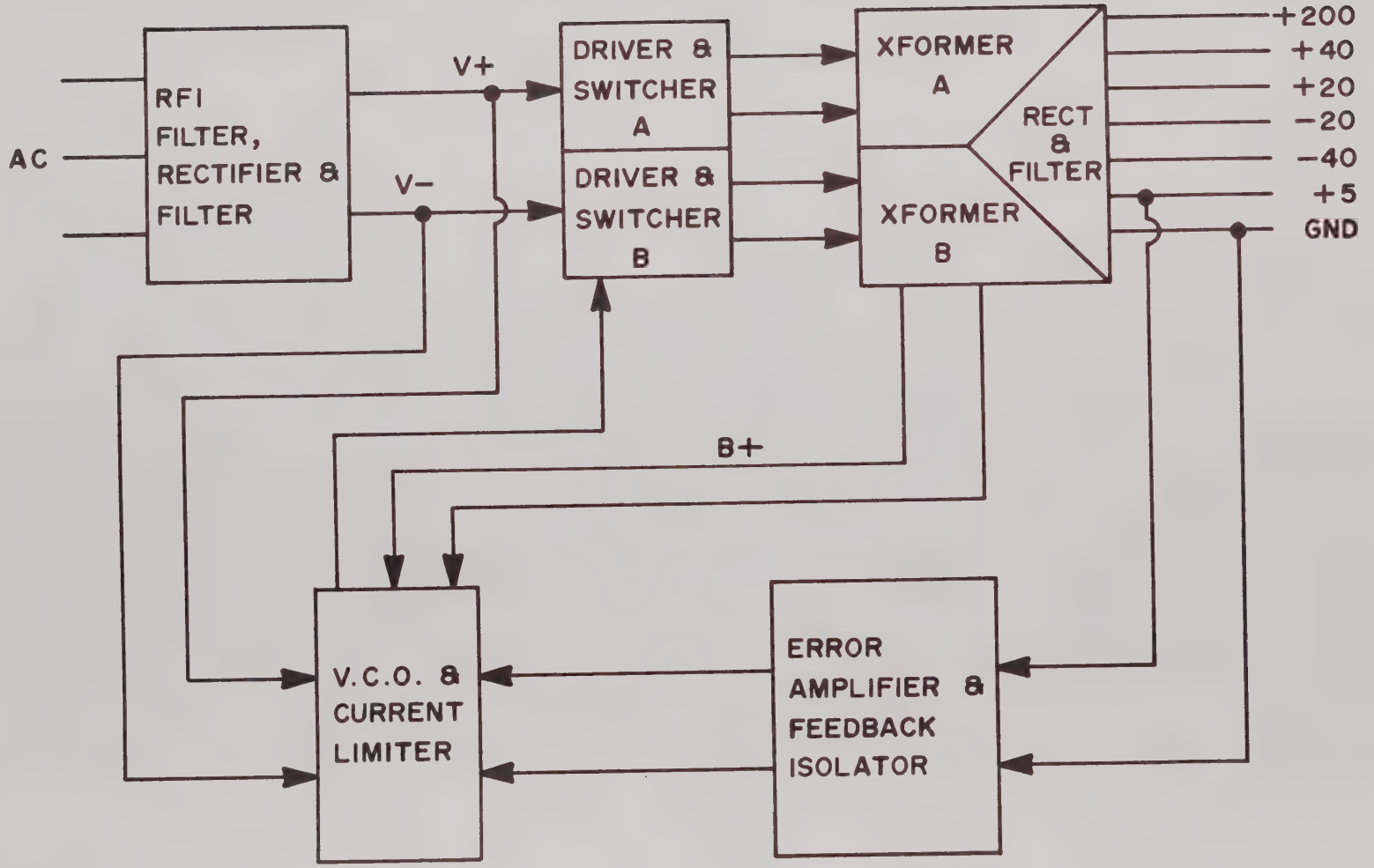


Figure 7-2. Block Diagram for the Model 444 Power Supply

The natural behavior of an electromagnetic circuit is to oppose any sudden change of current in the inductor by trying to maintain an equal but opposite magnetic field. This opposing magnetic field will generate reverse potentials on all the electrical windings of the transformer until the rectifier diodes are forward biased. At that instance, the magnetic energy is transformed into electrical energy, and the secondary circuits will then filter and store the energy to provide a DC output. One of these secondary outputs is the oscillator operating voltage as mentioned earlier.

The controlling feedback circuit operates from the +20 volt output. This circuit will compare the +5 volt output to an adjustable reference voltage, amplify the error and generate a DC level. This level is the controlling voltage to the voltage-controlled oscillator. Isolation is accomplished via an optoisolator.

D. Troubleshooting Procedure

It is recommended that the supply be serviced only by trained personnel. Before attempting to troubleshoot this power supply, confirm that the fault is with the power supply and not with the associated circuits.

Safety Precautions

1. Always use an isolated, variable AC power source for the power supply during troubleshooting.

2. Always remove input power before adding on or removing components from the power supply.

Troubleshooting

Note the mode of failures on the power supply and follow the procedure indicated.

1. All output voltages low (O.V.). See Fig. 7-3.

2. Has +5 volt output, but one or more of the other voltages are low or missing; +5 volt output normal, but one or more of the other outputs are either high or low. This does not include high voltage CRT outputs.

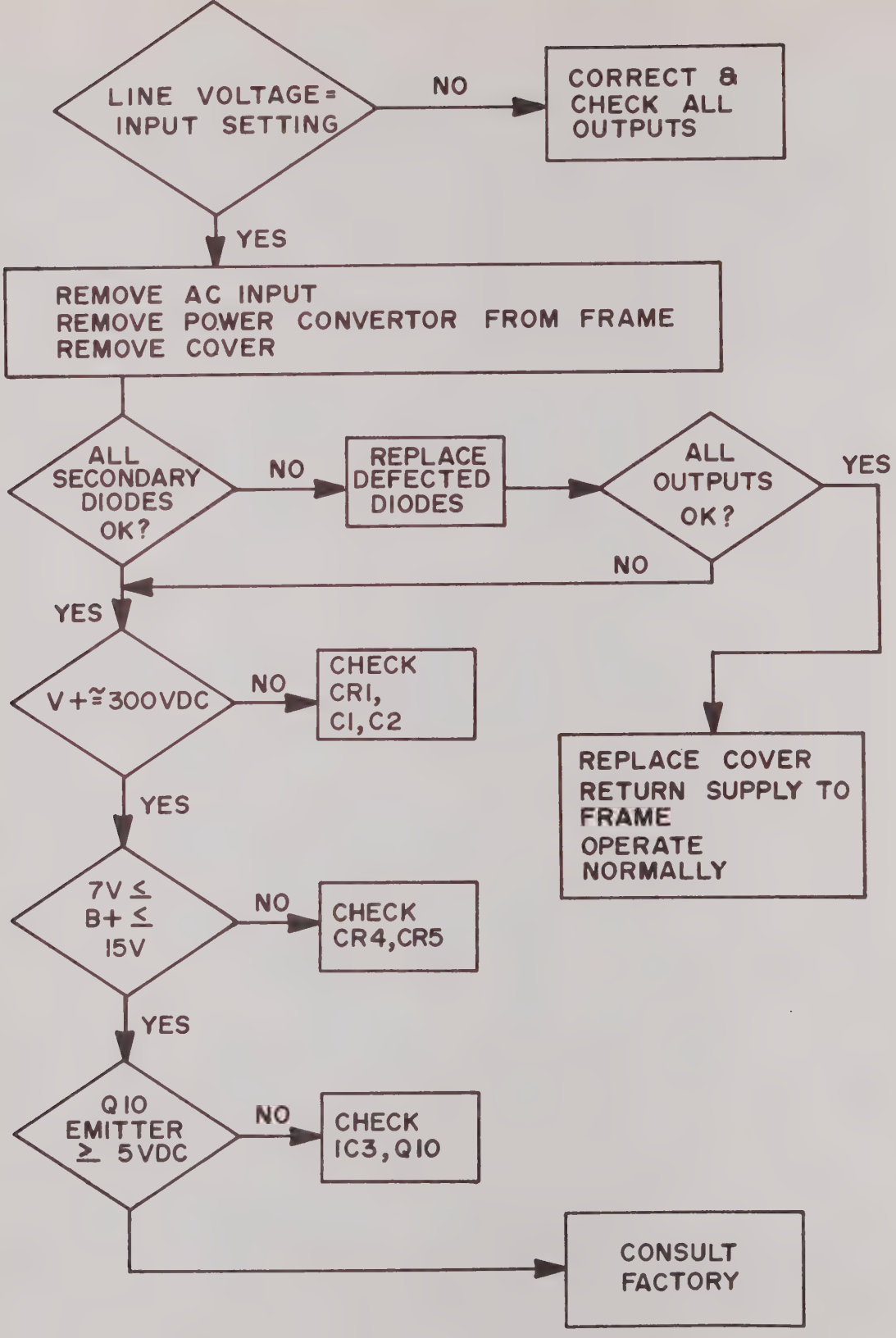


Figure 7-3. All Output Voltages Low

a. Check +15 and -15 output first.

b. If +15 and -15 are normal, then check +30 and -30 outputs. Replace regulator related to the abnormal outputs.

For +175 volt output, if output is high, check the series transistor. If output is low, check the feedback transistor.

WARNING: Do not attempt to troubleshoot high voltage convertor.

3. High ripple on one or more of the outputs. Replace 6.8 uf capacitor from the abnormal output regulator.

4. AC main fuse blown. See Figure 7-4.

5. AC supply fuse blown. See Figure 7-5.

6. Repeated thermal shutdown occurred. Check fan. If fan is running and there is no obstruction to air flow, consult factory.

E. Power Supply Adjustments

There are five adjustments available to the user for setting the systems' operating voltages. Table 7-2 lists the location of the controls, the recommended monitoring points and the correct voltage settings.

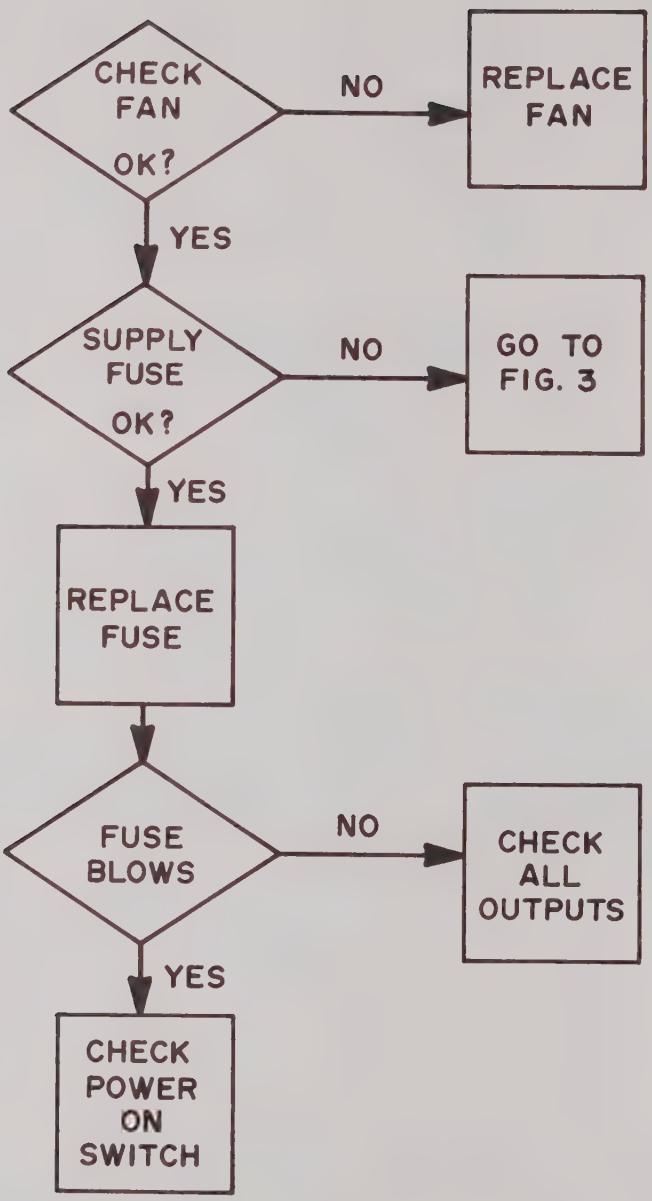


Figure 7-4. AC Main Fuse Blown

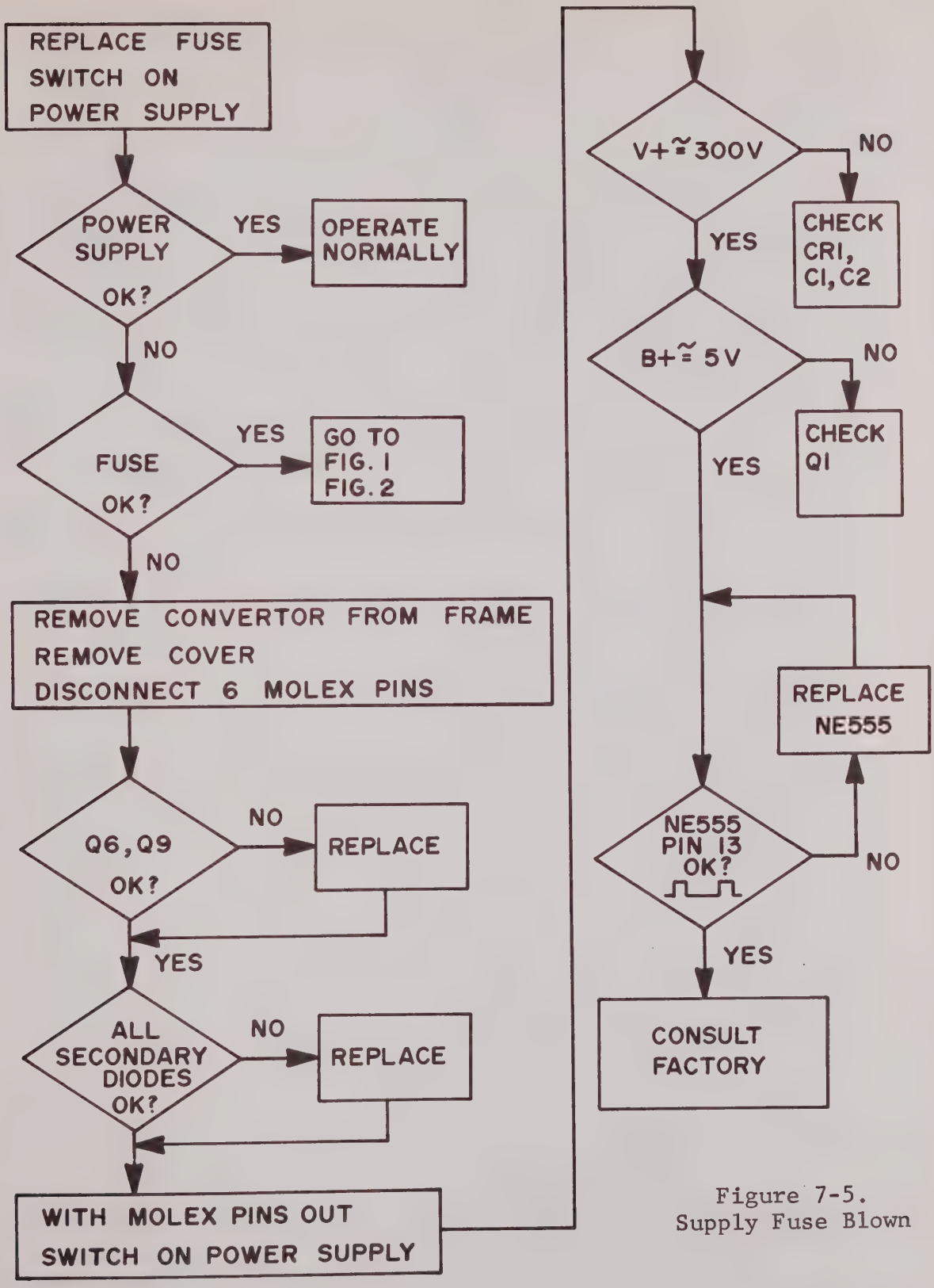


Figure 7-5.
Supply Fuse Blown

Table 7-2
Voltage Adjustments

Voltage/ Control	Adjustment Location	Monitoring Points	Voltage Settings
+5 volts	Rear Panel - Lower Left Corner	a. Program Control Board - Input side of fuse	5.0 volts
		b. Arithmetic Unit Input side of fuse	5.1 volts
		c. Rear Panel - Monitor Point	5.2 volts
+15 volts	See Fig. 7-6	See Fig. 7-1	+15 volts ±100 mv
+30 volts	See Fig. 7-6	See Fig. 7-1	+30 volts ±100 mv
-15 volts	See Fig. 7-6	See Fig. 7-1	-15 volts ±100 mv
-30 volts	See Fig. 7-6	See Fig. 7-1	-30 volts ±100 mv
+175 volts	Not Adjustable		
+1500 volts	Not Adjustable		
-1500 volts	Not Adjustable		
6.3 volts	Not Adjustable		
FOCUS	Refer to Section 7-5		
INTENSITY	Refer to Section 7-5		

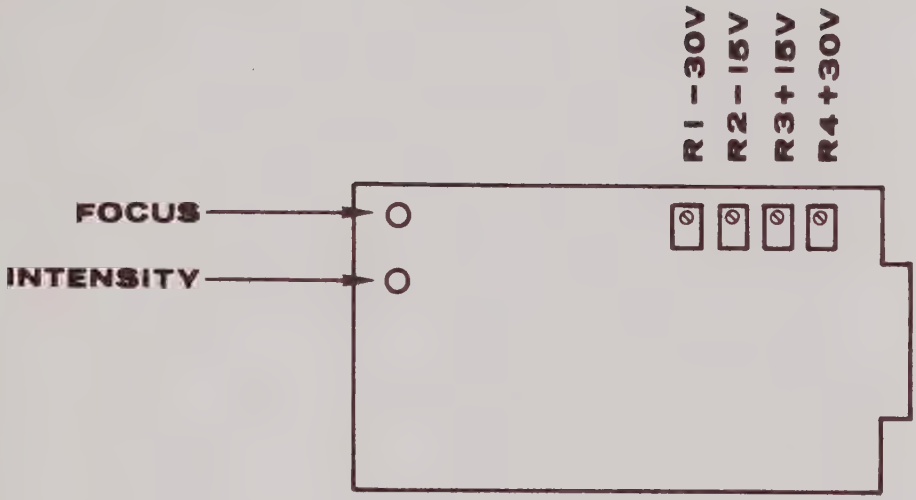


Figure 7-6. ±15, ±30 Volt Adjustment Location

SECTION VIII

–2 EXPANSION PLUG-IN OPTION

8-1. Frequency Expansion Option

This section describes the operating controls, theory of operation, and checkout procedure for the -2 EXPANSION PLUG-IN Option, shown in Figure 8-1, below.

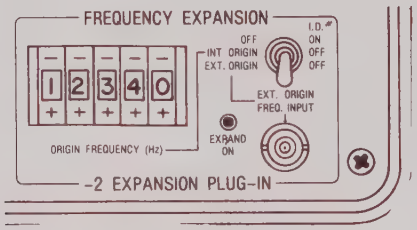


FIGURE 8-1. -2 EXPANSION PLUG-IN

8-2. -2 EXPANSION PLUG-IN Front Panel Controls

A. OFF/INT. ORIGIN/EXT. ORIGIN

1. OFF - This position of the switch bypasses the FREQUENCY EXPANSION function and permits normal operation. In this mode the FREQUENCY RANGE of the analyzer extends from 0 Hz to the maximum frequency indicated by the FREQUENCY RANGE switch.

2. INT. ORIGIN - This switch position enables the FREQUENCY EXPANSION function. In this mode of operation, the frequency axis of the display is expanded to cover a 100-Hz range starting at the frequency set on the ORIGIN FREQUENCY (Hz) digital switch.

Note

100 Hz is the standard filter bandwidth supplied with the -2 EXPANSION PLUG-IN Option. Bandwidths of 10, 20, 50, 500, 1,000, 2,000, 10,000 and 20,000 Hz are available as options.

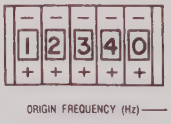
The ORIGIN FREQUENCY (Hz) may be varied from 100 Hz (or the optional filter bandwidth) to 99,900 Hz. Although operation is possible with the origin frequency below 100 Hz, spurious signals may be generated which will be visible on the spectrum display. If a spectrum display below 100 Hz is desired, it is advisable to use the standard lowpass ranges of the 444 Spectrum Analyzer.

3. EXT. ORIGIN - In this position operation of the frequency expansion function is similar to that described in paragraph 2, above, except that the ORIGIN FREQUENCY is determined by an external frequency reference source, applied to the EXT. ORIGIN FREQ INPUT connector.

B. EXTernal ORIGIN FREQuency INPUT

In the EXT. ORIGIN mode a 1-volt RMS sinusoidal signal applied to this connector will determine the origin frequency. The frequency of the signal applied to this connector is 100 kHz plus the desired origin frequency. The origin frequency is subject to the same limitations outlined in paragraph A-2, above.

C. ORIGIN FREQUENCY (Hz)



The ORIGIN FREQUENCY (Hz) digital switch is used to select the location of the lower frequency edge of the 100 Hz filter bandwidth when the INT. ORIGIN mode of operation is selected. This digital switch may be adjusted in 10-Hz steps from 00000 to 99990 Hz although only the range from 00100 to 99900 should be used.

D. EXPAND ON Indicator

This light emitting diode is illuminated whenever the Frequency Expansion function is ON.

8-3. -2 EXPANSION PLUG-IN Checkout

This procedure requires the use of a sinusoidal signal generator (audio oscillator).

A. Set front panel as shown in Table 4-1 with the following exceptions:

1. TEST/AC/DC in AC
2. FREQUENCY RANGE in 500 Hz
3. FREQUENCY EXPANSION/OFF/INT. ORIGIN
   EXT. ORIGIN in OFF
4. CURSOR: FREQ/OFF

B. Set ANNOTATION switch on rear panel to the FULL position.

C. Apply a 100 MV RMS, 250* Hz sinusoidal signal to the INPUT SIGNAL connector on the front panel. (See page 8-3a.)

D. Set the ORIGIN FREQUENCY (Hz) digital switch to 00200 Hz.

E. Observe that the display is a single spectral line centered on the frequency axis.

F. Place the FREQUENCY EXPANSION/OFF/INT. ORIGIN/EXT. ORIGIN in the INT. ORIGIN position.

G. Observe the display remains as describe in paragraph E, above, except that the frequency range annotation now reads 100.

Note

If optional filter bandwidth ranges have been installed, then frequency range annotation field should match the range installed.

H. Change the setting of the ORIGIN FREQUENCY (Hz) digital switch to 00160*. Observe that the display remains the same except that the spectral line (corresponding to the input signal frequency) is now located at the ninth tic mark on the horizontal axis.

*For Expansion Ranges other then 100 Hz, use the following settings in place of those given above:

Optional Filter Bandwidth	Line A2	C	D	H
10	500	205	00200	00200
20	500	225	00220	00210
50	500	245	00220	00200
100 STD	500	250	00200	00160
500	2,000	1,000	00750	00550
1,000	5,000	2,500	02000	01600
2,000	10,000	5,000	04000	03200
10,000	40,000	20,000	15000	11000
20,000	100,000	50,000	40000	32000

NOTE: For the 50 Hz filter, the signal is not centered in display for Step E.

For the 20 Hz filter, the signal is not centered in display Step E. In Step G the the display is at 25 percent of the window. For step H it will be shifted to 75 percent.

For the 10 Hz filter, the signal is not centered in display Step E. For Step H do not change ORIGIN setting. Instead change input frequency to 209 Hz. Note signal appears near ninth tic.

8-4. -2 EXPANSION PLUG-IN Block Diagram Description

This section presents a block diagram description of the -2 EXPANSION PLUG-IN FREQUENCY EXPANSION circuitry.

When either of the frequency expansion modes (INT. or EXT. ORIGIN) is selected, the input signal is applied through a buffer amplifier to a double balanced mixer (DBM). The origin frequency signal, either from the internal synthesizer or from the external origin frequency source is also applied to the DBM.

The output of the DBM is amplified and drives a lower sideband crystal filter. This filter limits the bandwidth of the input signal to 100 Hz (optional bandwidths of 50, 500, 1000, and 2000 Hz are available). The origin frequency control allows the lower frequency edge of the 100-Hz bandwidth to be moved from 100 Hz to 99900 Hz.

The output of the crystal filter is buffered and is applied to another DBM. In this mixer the filter output is shifted down in frequency until the origin of the 100-Hz bandwidth is 10 Hz. This output is applied directly to the input anti-aliasing filters of the 444 Spectrum Analyzer.

8-5. Changing Filter Bandwidths in the -2 EXPANSION PLUG-IN

The standard filter bandwidth for the -2 EXPANSION PLUG-IN is 100 Hz. Optional filters of 50, 500, 1000, and 2000 Hz are available and may be readily interchanged. The following procedure outlines the steps necessary to interchange Down Converter and Filter Board subassemblies to effect changes in filter bandwidth:

A. Turn OFF the power switch on the Model 444.

B. Unlock and remove the lower front panel drawer. This drawer is connected to the mainframe by a folding cable assembly. Do not remove these cables.

C. Locate the Down Converter and Filter Board Assembly. It is situated in the extreme right-hand position within the drawer directly behind the HOLD/REL pushbutton.

D. Carefully remove the Down Converter and Filter Board from its mounting socket. Disconnect the coaxial cable running between the Down Converter and Filter Board and the Up Cconverter Board.

E. Insert the replacement Down Converter and Filter Board into the proper socket in the drawer assembly. Reconnect the coaxial cable to the Up Converter Board.

F. Check that all boards and connectors are seated securely within the drawer.

G. Replace the drawer assembly into the Model 444 mainframe and secure the drawer lock. This completes the procedure.

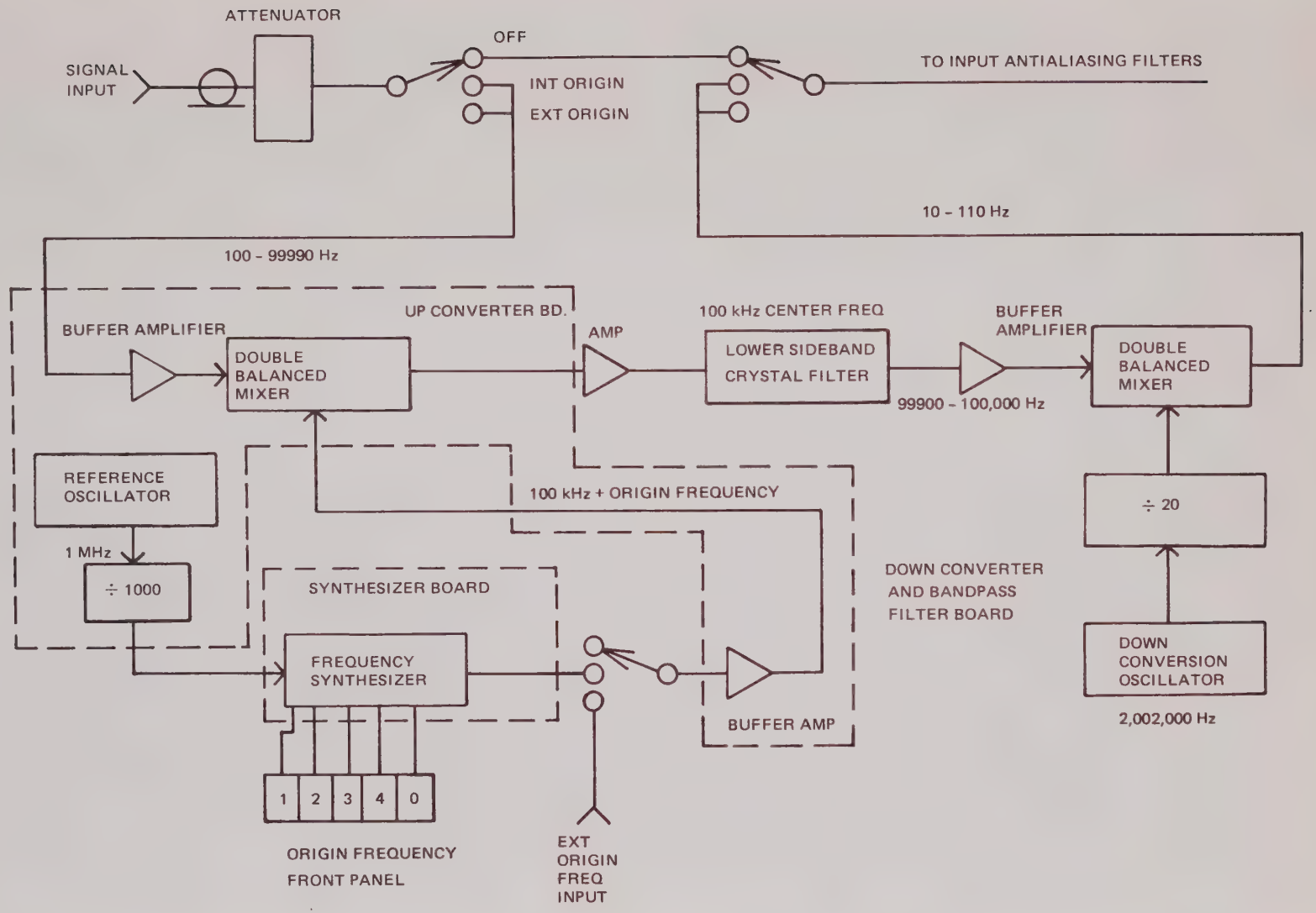


FIGURE 8-4. BLOCK DIAGRAM, -2 EXPANSION PLUG-IN

8-1. Overall View

The UA-444 is comprised of four major blocks of circuitry (see Figure 1). The main purpose of the Option 05 is to confirm that a majority of the Digital Signal Processor is operational. For the Option to work, the Display Circuits and CRT must be operational so that when malfunctions are found, they can be presented on the CRT screen. For this reason, there exists the capability within the Option to confirm that the Display Circuits and CRT are functional. Referring back to Figure 1, one can see that two major blocks have not been tested by the Option 05. They are the Front End Section and Power Supply. These two blocks must be serviced by conventional means. There exists an indication of power supply operation on the front panel, namely, the POWER ON lamp. There also exists an indication of front end operation, namely, the test mode of the AC, DC TEST switch. So one can see that within the 444 there are several built-in aids useful in servicing the instrument.

8-2. Processor Section

Referring to Figure 2, one can see that the processor section is made up of nine major blocks. Although the Option 05 exercises just over two of these major blocks, the circuits tested comprise approximately 375 of the 525 IC's within the unit or 70 percent of the processor section. Also, in order for Option 05 to work successfully, the "Decoder Proms" and the "Program Counter" must also work, accounting for an additional five percent of the processor unit. The "Misc Instruction Decoder" and the "Program Memory" is not tested by the Option 05 but going on past experience, they have accounted for a very small percentage of the UA-444's failure.

8-3. Using the Option 05

All the circuits tested by the Option 05 can be divided into two major categories. The first being the hardwired logic and the second being the random access memories, (RAMS). Since testing of the random access memories is a comparatively long test with respect to the hardwired logic, there is provision via a front panel switch to select whether or not the RAMS are tested in addition to the hardwired logic. To enable the Option 05, proceed as follows:

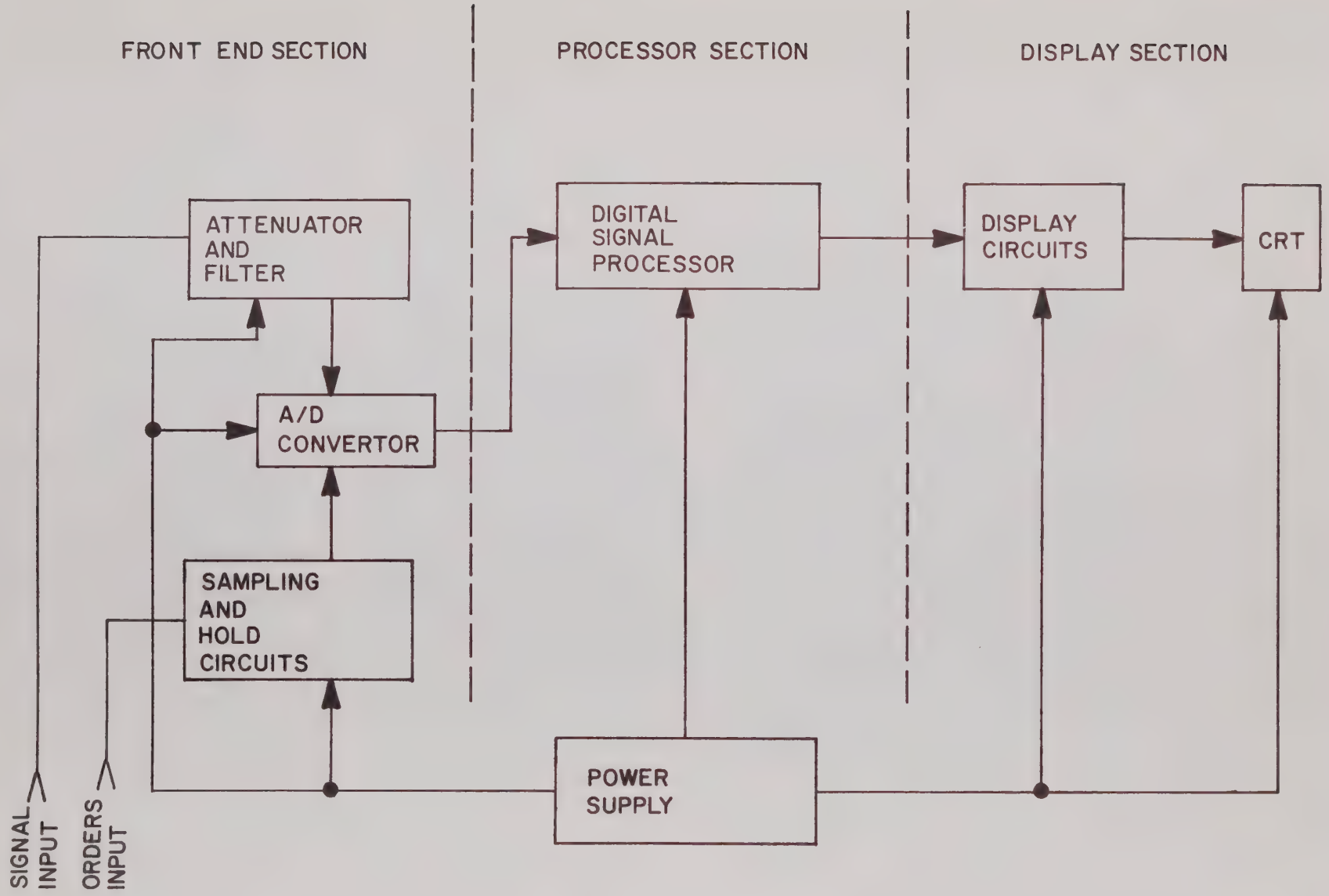


Figure 1. Overall Block Diagram

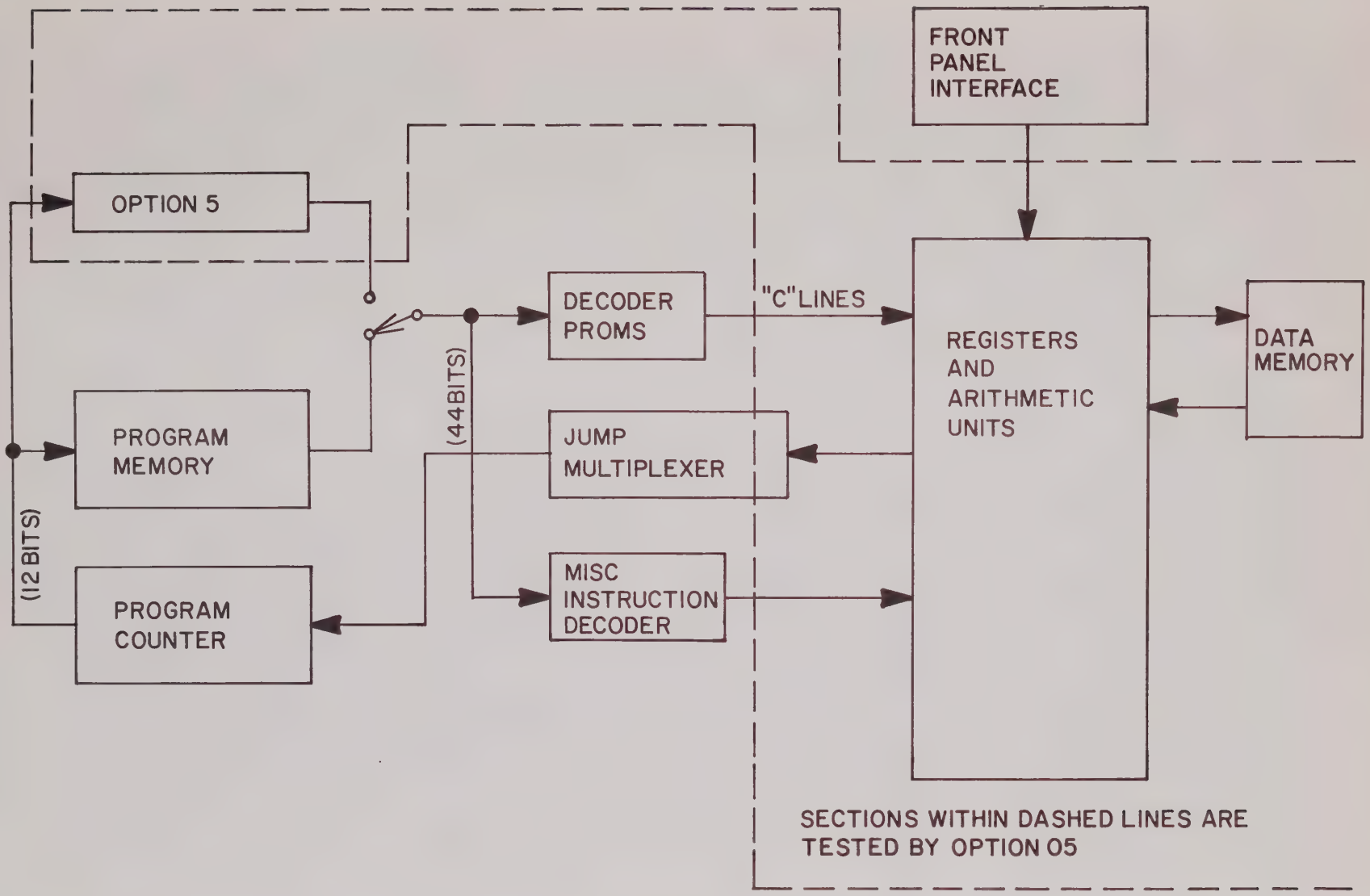


Figure 2. Processor Block Diagram

a. Depress the CONT A switch on the front panel and hold the button.

b. Depress the START A switch on the front panel without releasing the CONT A switch.

c. Continue to hold both switches depressed for about three seconds or until the CRT display disappears.

The position of the CURSOR switch will determine whether or not the RAMS are tested. When the cursor is off, the RAMS are not tested. When the cursor is either "Single" or "Harmonic" the RAMS are tested. The total time for the test is as follows:

a. Hardwired Logic Alone - about one second each successful pass through the Option 05 routine. The averager IN PROCESS light will flash on every alternate pass through the routine.

b. Hardwired Logic and RAMS - about one minute for each successful pass through the Option 05 routine. The "tree" (amplitude level lights on lower front panel) will be illuminated for about 50 percent of the time for each pass and the averager IN PROCESS light will flash at a rapid rate.

In order to test the CRT circuits, merely depress the STOP A button while the Option 05 is running. Three rows of ones and zeros should appear on the CRT screen, confirming that if an error is found by the Option 05, it can be displayed on the CRT. To clear the CRT display, merely depress the START A button to proceed with the Option 05 routine. Note: it is possible to have an error displayed on the CRT the first time the Option 05 is enabled. If this happens, merely depress the START A button again to restart the Option 05.

When the Option 05 is running, the averager IN PROCESS light will flash at either of the two rates mentioned above; but when an error is detected, the light will remain in a steady state (either always on or always off) and the CRT will display three rows of ones and zeros. This is not true when the Option 05 is running and the STOP A button is pushed. In this case, the CRT will display the three rows of ones and zeros, but the averager IN PROCESS light will continue to flash indicating the Option 05 is still running. Therefore, it is obvious that once the CRT circuits are confirmed to be working by depressing the STOP A button, the START A button must be depressed to clear the

display and allow any error found by the Option 05 to be displayed. The Option 05 will continue running indefinitely unless it finds an error, at which point it will stop and display the error. Once an error has been detected, it is advisable to record the error on a piece of paper and then depress the START A button causing the Option 05 to begin again. Depending on whether or not the same error, if any, is again detected by the Option 05, you will have an idea if the failure is intermittent or permanent. To return the analyzer to its normal mode of operation, simply depress the RESET button (on the rear panel).

8-4. Locating IC's to be Replaced

All the IC's listed in this code book are located on two of the three main processor boards. Namely, the Arithmetic Unit (AU) and Program Control (PC) boards. To gain access to these boards, proceed as follows.

a. Shut off power.

b. Remove right-hand side dust cover.

c. Unclip the nylon rod from the outside board.

d. Unscrew the two screws located in the upper corners of the board.

e. Hinge down the outside board. Be careful to use the nylon rod to act as a support when the board is down.

Now the two boards that are exposed are the AU board (board hinged down) and the PC board (board still in a vertical position). You will note that both boards have IC's on the same grid coordinate system except that the AU board has provision for 24 pin IC's at the edge of the board, labeled IC1 through IC12. The remaining IC's are a Row/Column grid. Therefore, to locate an IC such as AU-C17, proceed as follows:

a. Locate the "C" row of the AU board (stencilled along the width of the board).

b. Locate the "17" column of the AU board (stencilled along the length of the board).

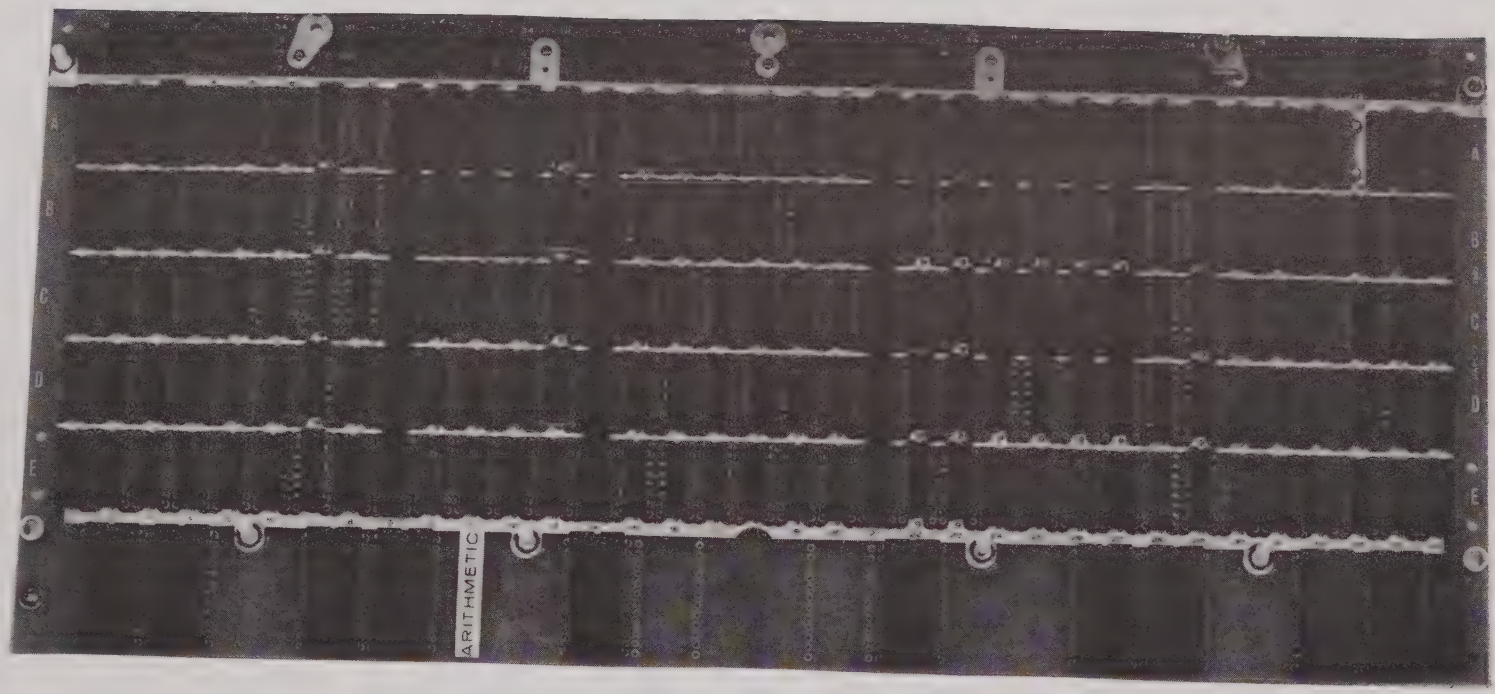


Figure 3. Typical IC Layout

c. The IC located at the intersection of the "C" row and "17" column is the IC desired.

d. Using the IC extractor tool supplied, carefully remove the IC and replace.

On the AU board the markings for IC1 through IC12 are not clearly visible (almost covered by the IC itself). To locate one of these, simply start counting from the front of the unit. Therefore IC1 would be the 24 pin IC closest to the front of the unit and IC12 would be the IC closest to the rear of the unit.

8-5. Reading the Error Code

When an error is detected by the Option 05, three lines of ones and zeros will appear on the CRT screen such as shown in Figure 4. You can see that the top two lines contain twenty characters each and the third line contains ten characters with several blanks. The twenty characters of the top two lines are numbered D0 through D19. (D0 is the left-hand character.) The third line is an address to be read in octal format. (See Figure 4.) In most but not all cases, the top line indicates the correct answer for the particular test in process and the second line indicates the actual answer received. In the example shown in Figure 4, an error occurred at address 0172 in bit positions D0, D1, and D2, since those are the only three bits that differ between the top two lines.

8-6. Reading the Code Book

The code book is divided into three columns. The first column is the error address. The second column indicates which bit positions (D0 through D19) have failed. Some failures do not require noting which bits are in error and for these situations Column 2 is left blank and the top two CRT lines can be ignored. The third column contains a list of the probable IC's that can cause the error. In the example shown in Figure 4, the error occurred at address 0172. Looking down the first column of the code book until address 0172, we see that address 0172 appears five times. What differs between these five errors is Column 2. Referring back to Figure 4 we see that the top two lines differ from each other in bit positions D0, D1, and D2. Returning back to the code book, it should be obvious that the error of interest could be the first one since the second

```
D - 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
    0 1 0 1 1 0 0 1 0 1 0  1  1  1  1  0  0  1  1  0
    1 0 1 1 1 0 0 1 0 1 0  1  1  1  1  0  0  1  1  0
          0     0 0 1     1  1  1        0  1  0
ADDRESS = 0       1           7              2
```

Octal Format for Third Line

0 0 0 = 0

0 0 1 = 1

0 1 0 = 2

0 1 1 = 3

1 0 0 = 4

1 0 1 = 5

1 1 0 = 6

1 1 1 = 7

Figure 4. Typical 05 CRT Pattern

column reads D0 through D3. The third column gives the IC's that would most probably cause this error. They are IC12, A35, A29, A31, and A30 of the Arithmetic Unit (AU) Board. Another example might be an error at address 0106. Looking down the first column of the Code Book, you see that the top two lines of the display are meaningless (because the second column is blank) and the suspect IC's are D28 or E28 of the AU Board or B26 or B28 of the PC Board.

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S

(1) RI DIAGNOSTICS PORTION

0004		PC-C7, D7, E7, C6, D6, E6, C5, D5, E5, D3, E3, D4, E4, B25, B28
0006*	D0->D3	AU-IC1, A2, A4, A5, A6, A7
0006*	D4->D7	AU-IC2, B2, B3, B4, B5, B6, B7
0006*	D8->D11	AU-IC3, C2, C3, C4, C5, C6, C7
0006*	D12->D15	AU-IC4, D2, D3, D4, D5, D6, D7
0006*	D16->D19	AU-IC5, E2, E3, E4, E5, E6, E7
*	NOTE: D0->D19 ARE OK; PC-B27, B28	
0007*	D0->D3	AU-IC1, A1, A5, A6
0007*	D4->D7	AU-IC2, B1, B5, B6
0007*	D8->D11	AU-IC3, C1, C5, C6
0007*	D12->D15	AU-IC4, D1, D5, D6
0007*	D16->D19	AU-IC5, E1, E5, E6
*	NOTE: D0->D19 ARE OK; PC-B27, 28	
0012*	D0->D3	AU-IC12, A29, A30, A31, A32, A34, A35
0012*	D4->D7	AU-IC11, B29, B30, B31, B32, B33, B34, B35
0012*	D8->D11	AU-IC10, C29, C30, C31, C32, C33, C34, C35
0012*	D12->D15	AU-IC9, D29, D30, D31, D32, D33, D34, D35
0012*	D16->D19	AU-IC8, E29, E30, E31, E32, E33, E34, E35
*	NOTE: D0->D19 ARE OK; AU-IC8, IC9, IC10, IC11, IC12; PC-B27, B28	
0013*	D0->D3	AU-IC12, A29, A30, A31, A32, A34, A35
0013*	D4->D7	AU-IC11, B29, B30, B31, B32, B33, B34, B35
0013*	D8->D11	AU-IC10, C29, C30, C31, C32, C33, 334, 335
0013*	D12->D15	AU-IC9, D29, D30, D31, D32, D33, D34, D35
0013*	D16->D19	AU-IC8, E29, E30, E31, E32, E33, E34, E35
*	NOTE: D0->D19 ARE OK; AU-IC8, IC9, IC10, IC11, IC12; PC-B27, B28	
0014		PC-B31
0015		AU-IC8, IC9, IC10, IC11, IC12
0016*	D0->D3	AU-IC12, A29, A30, A31, A32, A34, A35
0016*	D4->D7	AU-IC11, B29, B30, B31, B32, B33, B34, B35
0016*	D8->D11	AU-IC10, C29, C30, C31, C32, C33, C34, C35
0016*	D12->D15	AU-IC9, D29, D30, D31, D32, D33, D34, D35
0016*	D16->D19	AU-IC8, E29, E30, E31, E32, E33, E34, E35
*	NOTE: D0->D19 ARE OK; AU-IC8, IC9, IC10, IC11YIC12; PC-B27, B28	
0021	D0->D3	AU-A4, C13, B23
0021	D4->D7	AU-B4
0021	D8->D11	AU-C4
0021	D12->D15	AU-D4
0021	D16->D19	AU-E4
0022		AU-A1, IC1, A5, A7
0024	D0->D3	AU-IC12, A29, A30, A31, A32, A34
0024	D4->D7	AU-IC11, B29, B30, B31, B32, B33, B34
0024	D8->D11	AU-IC10, C29, C30, C31, C32, C33, C34
0024	D12->D15	AU-IC9, D29, D30, D31, D32, D33, D34
0024	D16->D19	AU-IC8, E29, E30, E31, E32, E33, E34
0026	D0->D3	AU-IC12, A29, A30, A31, A32, A34
0030	D0->D3	AU-IC12, A35, A29, A31, A30
0030	D4->D7	AU-IC11, B35, B29, B31, B30
0030	D8->D11	AU-IC10, C35, C29, C31, C30
0030	D12->D15	AU-IC9, D35, D29, D31, D30
0030	D16->D19	AU-IC8, E35, E29, E31, E30

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S
0031	D0->D3	AU-IC12
0031	D4->D7	AU-IC12
0031	D8->D11	AU-IC10
0031	D12->D15	AU-IC9
0031	D16->D19	AU-IC8
0032	D0->D3	AU-IC12
0032	D4->D7	AU-IC11
0032	D8->D11	AU-IC10
0032	D12->D15	AU-IC9
0032	D16->D19	AU-IC8
0034	D0->D3	AU-IC1
0034	D4->D7	AU-IC2
0034	D8->D11	AU-IC3
0034	D12->D15	AU-IC4
0034	D16->D19	AU-IC5
0036	D0->D3	AU-IC1
0036	D4->D7	AU-IC2
0036	D8->D11	AU-IC3
0036	D12->D15	AU-IC4
0036	D16->D19	AU-IC5
0040		AU-IC1; PC-B27,B28
0041		AU-IC1; PC-B27,B28
0043		AU-A4
0046		AU-IC12; PC-B27,B28
0047		AU-IC12; PC-B27,B28
0050		AU-A1

(2) VC-LOAD, COUNT AND SENSE CARRY

0052	D0->D3	AU-D28
0052	D4->D7	AU-E28
0056	D0->D3	AU-D28
0056	D4->D7	AU-E28
0061	D0->D3	AU-D28
0061	D4->D7	AU-E28
0064	D0->D3	AU-D28
0064	D4->D7	AU-E28
0067	D0->D3	AU-D28
0067	D4->D7	AU-E28
0072	D0->D3	AU-D28
0072	D4->D7	AU-E28
0075	D0->D3	AU-D28
0075	D4->D7	AU-E28
0100	D0->D3	AU-D28
0100	D4->D7	AU-E28
0103	D0->D3	AU-D28
0103	D4->D7	AU-E28
0106		AU-D28,E28; PC-B26,B28
0111		AU-D28,E28
0113		AU-D28,E28; PC-B26,B28
0114		AU-D28,E28

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S

(3) PROGRAM FLAG TESTS

0117		PC-C18, D18, E18, C23, C24, B24, B28
0120		PC-C18, D18, E18, C23, C24, B24, B28
0122		PC-C18, D18, E18, C23, C24, B24, B28
0124		PC-C18, D18, E18, C23, C24, B24, B28
0126		PC-C18, D18, E18, C23, C24, B24, B28
0130		PC-C18, D18, E18, C23, C24, B24, B28

(4) RI SHIFT RIGHT LOGICAL & ARITH TESTS

0133	D0->D3	AU-IC1, A1, A2, A4, A5, A6, A7
0133	D0->D3	AU-IC12, A29, A30, A31, A32, A34, A35
0133	D4->D7	AU-IC2, B1, B2, B3, B4, B5, B6, B7
0133	D4->D7	AU-IC11, B29, B30, B31, B32, B33, B34, B35
0133	D8->D11	AU-IC3, C1, C2, C3, C4, C5, C6, C7
0133	D12->D15	AU-IC4, D1, D2, D3, D4, D5, D6, D7
0133	D12->D15	AU-IC9, D29, D30, D31, D32, D33, D34, D35
0133	D16->D19	AU-IC5, E1, E2, E3, E4, E5, E6, E7
0133	D16->D19	AU-IC8, E29, E30, E31, E32, E33, E34, E35
0134	D0->D3	AU-IC1, A2, A4, A5, A6, A7
0134	D4->D7	AU-IC2, B2, B3, B4, B5, B6, B7
0134	D8->D11	AU-IC3, C2, C3, C4, C5, C6, C7
0134	D12->D15	AU-IC4, D2, D3, D4, D5, D6, D7
0134	D16->D19	AU-IC5, E2, E3, E4, E5, E6, E7
0135	D0->D3	AU-IC12, A29, A30, A31, A32, A34
0135	D4->D7	AU-IC11, B29, B30, B31, B32, B33, B34
0135	D8->D11	AU-IC10, C29, C30, C31, C32, C33, C34
0135	D12->D15	AU-IC9, D29, D30, D31, D32, D33, D34
0135	D16->D19	AU-IC8, E29, E30, E31, E32, E33, E34
0136	D0->D3	AU-IC1, A1, A5, A6
0136	D4->D7	AU-IC2, B1, B5, B6
0136	D8->D11	AU-IC3, C1, C5, C6
0136	D12->D15	AU-IC4, D1, D5, D6
0136	D16->D19	AU-IC5, E1, E5, E6
0137	D0->D3	AU-IC1, A2, A4, A5, A6, A7
0137	D4->D7	AU-IC2, B2, B3, B4, B5, B6, B7
0137	D8->D11	AU-IC3, C2, C3, C4, C5, C6, C7
0137	D12->D15	AU-IC4, D2, D3, D4, D5, D6, D7
0137	D16->D19	AU-IC5, E2, E3, E4, E5, E6, E7
0140	D0->D3	AU-IC12, A35, A29, A31, A30
0140	D4->D7	AU-IC11, B35, B9, B31T230
0140	D8->D11	AU-IC10, C35, C29, C31, C30
0140	D12->D15	AU-IC9, D35, D29, D31, D30
0140	D16->D19	AU-IC8, E35, E29, E31, E30
0141	D0->D3	AU-IC12, A29, A30, A31, A32, A34
0141	D4->D7	AU-IC11, B29, B30, B31, B32, B33, B34
0141	D8->D11	AU-IC10, C29, C30, C31, C32, C33, C34
0141	D12->D15	AU-IC9, D29, D30, D31, D32, D33, D34
0141	D16->D19	AU-IC8, E29, E30, E31, E32, E33, E34

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S
0153	D0->D3	AU-IC1, A2, A4, A5, A6, A7
0153	D4->D7	AU-IC2, B2, B3, B4, B5, B6, B7
0153	D8->D11	AU-IC3, C2, C3, C4, C5, C6, C7
0153	D12->D15	AU-IC4, D2, D3, D4, D5, D6, D7
0153	D16->D19	AU-IC5, E2, E3, E4, E5, E6, E7
0161	D0->D3	AU-IC1, A1, A5, A6
0161	D4->D7	AU-IC2, B1, B5, B6
0161	D8->D11	AU-IC3, C1, C5, C6
0161	D12->D15	AU-IC4, D1, D5, D6
0161	D16->D19	AU-IC5, E1, E5, E6
0162	D0->D3	AU-IC12, A35, A29, A31, A30
0162	D4->D7	AU-IC11, B35, B29, B31, B30
0162	D8->D11	AU-IC10, C35, C29, C31, C30
0162	D12->D15	AU-IC9, D35, D29, D31, D30
0162	D16->D19	AU-IC8, E35, E29, E31, E30
0163	D0->D3	AU-IC1, A2, A4, A5, A6, A7
0163	D4->D7	AU-IC2, B2, B3, B4, B5, B6, B7
0163	D8->D11	AU-IC3, C2, C3, C4, C5, C6, C7
0163	D12->D15	AU-IC4, D2, D3, D4, D5, D6, D7
0163	D16->D19	AU-IC5, E2, E3, E4, E5, E6, E7
0164	D0->D3	AU-IC12, A29, A30, A31, A32, A34
0164	D4->D7	AU-IC11, B29, B30, B31, B32, B33, B34
0164	D8->D11	AU-IC10, C29, C30, C31, C32, C33, C34
0164	D12->D15	AU-IC9, D29, D30, D31, D32, D33, D34
0164	D16->D19	AU-IC8, E29, E30, E31, E32, E33, E34

(5) RI SHIFT LEFT LOGICAL TEST

0171	D0->D3	AU-IC1, A1, A5, A6, A7, IC12, A29, A30, A31, A32, A34
0171	D4->D7	AU-IC2, B1, B5, B6, B7, IC11, B29, B30, B31, B32, B33, B34
0171	D8->D11	AU-IC3, C1, C5, C6, C7, IC10, C29, C30, C31, C32, C33, C34
0171	D12->D15	AU-IC4, D1, D5, D6, D7, IC9, D29, D30, D31, D32, D33, D34
0171	D16->D19	AU-IC5, E1, E5, E6, E7, IC8, E29, E30, E31, E32, E33, E34
0172	D0->D3	AU-IC12, A35, A29, A31, A30
0172	D4->D7	AU-IC11, B35, B29, B31, B30
0172	D8->D11	AU-IC10, C35, C29, C31, C30
0172	D12->D15	AU-IC9, D35, D29, D31, D30
0172	D16->D19	AU-IC8, E35, E29, E31, E30
0173	D0->D3	AU-IC1, A2, A4, A5, A6, A7
0173	D4->D7	AU-IC2, B2, B3, B4, B5, B6, B7
0173	D8->D11	AU-IC3, C2, C3, C4, C5, C6, C7
0173	D12->D15	AU-IC4, D2, D3, D4, D5, D6, D7
0173	D16->D19	AU-IC5, E2, E3, E4, E5, E6, E7
0174	D0->D3	AU-IC1, A2, A4, A5, A6, A7
0174	D4->D7	AU-IC2, B2, B3, B4, B5, B6, B7
0174	D8->D11	AU-IC3, C2, C3, C4, C5, C6, C7
0174	D12->D15	AU-IC4, D2, D3, D4, D5, D6, D7
0174	D16->D19	AU-IC5, E2, E3, E4, E5, E6, E7
0201	D0->D3	AU-IC1, A2, A4, A5, A6, A7
0201	D4->D7	AU-IC2, B2, B3, B4, B5, B6, B7
0201	D8->D11	AU-IC3, C2, C3, C4, C5, C6, C7
0201	D12->D15	AU-IC4, D2, D3, D4, D5, D6, D7
0201	D16->D19	AU-IC5, E2, E3, E4, E5, E6, E7

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S
0202	D0->D3	AU-IC1, A1, A5, A6
0202	D4->D7	AU-IC2, B1, B5, B6
0202	D8->D11	AU-IC3, C1, C5, C6
0202	D12->D15	AU-IC4, D1, D5, D6
0202	D16->D19	AU-IC5, E1, E5, E6
0203	D0->D3	AU-IC12, A29, A30, A31, A32, A34
0203	D4->D7	AU-IC11, B29, B30, B31, B32, B33, B34
0203	D8->D11	AU-IC10, C29, C30, C31, C32, C33, C34
0203	D12->D15	AU-IC9, D29, D30, D31, D32, D33, D34
0203	D16->D19	AU-IC8, E29, E30, E31, E32, E33, E34
0204	D0->D3	AU-IC12, A35, A29, A31, A30
0204	D4->D7	AU-IC11, B35, B29, B31, B30
0204	D8->D11	AU-IC10, C35, C29, C31, C30
0204	D12->D15	AU-IC9, D35, D29, D31, D30
0204	D16->D19	AU-IC8, E35, E29, E31, E30

(6) PROM ON "D" BUS TEST

0214		PC-B18, B19

(7) R1 FIXED SCALING TEST 1

0232		AU-A2, B2, B3, C2, C3, D2, D3, E2, E3
0234		AU-A34, B34, B33, C34, C33, D34, D33, E34, E33

(8) R1 FIXED SCALING TEST 2

0250		AU-A2, B2, B3, C2, C3, D2, D3, E2, E3
0252		AU-A34, B34, B33, C34, C33, D34, D33, E34, E33

(9) R1 FIXED SCALING TEST 3

0260	D0->D3	AU-IC12, A29, A30, A31, A32, A34, A35
0260	D4->D7	AU-IC11, B29, B30, B31, B32, B33, B34, B35
0260	D8->D11	AU-IC10, C29, C30, C31, C32, C33, C34, C35
0260	D12->D15	AU-IC9, D29, D30, D31, D32, D33, D34, D35
0260	D16->D19	AU-IC8, E29, E30, E31, E32, E33, E34, E35
0264	D0->D3	AU-IC12, A35, A29, A31, A30
0264	D4->D7	AU-IC11, B35, B29, B31, B30
0264	D8->D11	AU-IC10, C35, C29, C31, C30
0264	D12->D15	AU-IC9, D35, D29, D31, D30
0264	D16->D19	AU-IC8, E35, E29, E31, E30
0302	D0->D3	AU-IC12, A29, A30, A31, A32, A34, A35
0302	D4->D7	AU-IC11, B29, B30, B31, B32, B33, B34, B35
0302	D8->D11	AU-IC10, C29, C30, C31, C32, C33, C34, C35
0302	D12->D15	AU-IC9, D29, D30, D31, D32, D33, D34, D35
0302	D16->D19	AU-IC8, E29, E30, E31, E32, E33, E34, E35
0306		AU-A34, B34, B33, C34, C33, D34, D33, E34, E33
0316	D0->D3	AU-IC1, A1, A5, A6
0316	D4->D7	AU-IC2, B1, B5, B6
0316	D8->D11	AU-IC3, C1, C5, C6
0316	D12->D15	AU-IC4, D1, D5, D6
0316	D16->D19	AU-IC5, E1, E5, E6

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S
0326	D0->D3	AU-IC1, A1, A2, A4, A5, A6, A7
0326	D4->D7	AU-IC2, B1, B2, B3, B4, B5, B6, B7
0326	D8->D11	AU-IC3, C1, C2, C3, C4, C5, C6, C7
0326	D12->D15	AU-IC4, D1, D2, D3, D4, D5, D6, D7
0326	D16->D19	AU-IC5, E1, E2, E3, E4, E5, E6, E7
0333	D0->D3	AU-IC1, A1, A2, A4, A5, A6, A7
0333	D4->D7	AU-IC2, B1, B2, B3, B4, B5, B6, B7
0333	D8->D11	AU-IC3, C1, C2, C3, C4, C5, C6, C7
0333	D12->D15	AU-IC4, D1, D2, D3, D4, D5, D6, D7
0333	D16->D19	AU-IC5, E1, E2, E3, E4, E5, E6, E7

(10) RI MISC. TEST 1

0341	D0->D3	AU-A5, A6
0341	D4->D7	AU-B5, B6
0341	D8->D11	AU-C5, C6
0341	D12->D15	AU-D5, D6
0341	D16->D19	AU-E5, E6
0343	D0->D3	AU-A30, A31
0343	D4->D7	AU-B30, B31
0343	D8->D11	AU-C30, C31
0343	D12->D15	AU-D30, D31
0343	D16->D19	AU-E30, E31
0345	D0->D3	AU-IC1, A1, A2, A4, A5, A6, A7
0345	D4->D7	AU-IC2, B1, B2, B3, B4, B5, B6, B7
0345	D8->D11	AU-IC3, C1, C2, C3, C4, C5, C6, C7
0345	D12->D15	AU-IC4, D1, D2, D3, D4, D5, D6, D7
0345	D16->D19	AU-IC5, E1, E2, E3, E4, E5, E6, E7
0347	D0->D3	AU-A30, A31
0347	D4->D7	AU-B30, B31
0347	D8->D11	AU-C30, C31
0347	D12->D15	AU-D30, D31
0347	D16->D19	AU-E30, E31
0351	D0->D3	AU-A30, A31
0351	D4->D7	AU-B30, B31
0351	D8->D11	AU-C30, C31
0351	D12->D15	AU-D30, D31
0351	D16->D19	AU-E30, E31
0353	D0->D3	AU-IC12, A35, A29, A31, A30
0353	D4->D7	AU-IC11, B35, B29, B31, B30
0353	D8->D11	AU-IC10, C35, C29, C31, C30
0353	D12->D15	AU-IC9, D35, D29, D31, D30
0353	D16->D19	AU-IC8, E35, E29, E31, E30
0361	D0->D3	AU-IC12, A35, A29, A31, A30
0361	D4->D7	AU-IC11, B35, B29, B31, B30
0361	D8->D11	AU-IC10, C35, C29, C31, C30
0361	D12->D15	AU-IC9, D35, D29, D31, D30
0361	D16->D19	AU-IC8, E35, E29, E31, E30

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S
		(11) RI MISC. TEST 2
0367	D0->D3	AU-IC12, A35, A29, A31, A30
0367	D4->D7	AU-IC11, B35, B29, B31, B30
0367	D8->D11	AU-IC10, C35, C29, C31, C30
0367	D12->D15	AU-IC9, D35, D29, D31, D30
0367	D16->D19	AU-IC8, E35, E29, E31, E30
0372	D0->D3	AU-IC12, A35, A29, A31, A30
0372	D4->D7	AU-IC11, B35, B29, B31, B30
0372	D8->D11	AU-IC10, C35, C29, C31, C30
0372	D12->D15	AU-IC9, D35, D29, D31, D30
0372	D16->D19	AU-IC8, E35, E29, E31, E30
		(12) RI MISC. TEST 3
0377*	D0->D3	AU-IC1, A1, A5, A6, A7, IC12, A29, A30, A31, A32, A34
0377*	D4->D7	AU-IC2, B1, B5, B6, B7, IC11, B29, B30, B31, B32, B33, B34
0377*	D8->D11	AU-IC3, C1, C5, C6, C7, IC10, C29, C30, C31, C32, C33, C34
0377*	D12->D15	AU-IC4, D1, D5, D6, D7, IC9, D29, D30, D31, D32, D33, D34
0377*	D16->D19	AU-IC5, E1, E5, E6, E7, IC8, E29, E30, E31, E32, E33, E34
*	NOTE: THE	TOP 2 LINES SHOULD BE COMPLIMENTS OF EACH OTHER
0401	D0->D3	AU-IC1, A1, A5, A6
0401	D4->D7	AU-IC2, B1, B5, B6
0401	D8->D11	AU-IC3, C1, C5, C6
0401	D12->D15	AU-IC4, D1, D5, D6
0401	D16->D19	AU-IC5, E1, E5, E6
		(13) RI "P" ADD TEST
0407	D0->D3	AU-A30, A31, A5, A6
0407	D4->D7	AU-B30, B31, B5, B6
0407	D8->D11	AU-C30, C31, C5, C6
0407	D12->D15	AU-D30, D31, D5, D6
0407	D16->D19	AU-E30, E31, E5, E6
0416	D0->D3	AU-IC1, A1, A5, A6
0416	D4->D7	AU-IC2, B1, B5, B6
0416	D8->D11	AU-IC3, C1, C5, C6
0416	D12->D15	AU-IC4, D1, D5, D6
0416	D16->D19	AU-IC5, E1, E5, E6
		(14) RI ADD AND CARRY TEST 1
0420		AU-IC1; PC-B27, B28
0421		PC-A27, B27, B28
0423		AU-IC12; PC-B27, B28
0425		PC-A27, B27, B28
0430		PC-A27, B27, B28
0433		PC-A27, B27, B28
0437		AU-IC1, IC2, IC3, IC4, IC5
0444		AU-IC8, IC9, IC10, IC11, IC12
0446		AU-IC1; PC-B27, B28
0450		AU-IC1; PC-B27, B28
0452		AU-IC1, IC2, IC3, IC4, IC5; PC-B27, B28
0454		AU-IC8, IC9, IC10, IC11, IC12; PC-B27, B28

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S

(15) RI ADD AND CARRY TEST 2

0470	D0->D3	AU-IC1, IC12
0470	D4->D11	AU-IC2, IC3, IC11, IC10
0470	D12->D19	AU-IC4, IC5, IC9, IC8
0472	D0->D3	AU-IC1, A1, A5, A6
0472	D4->D7	AU-IC2, B1, B5, B6
0472	D8->D11	AU-IC3, C1, C5, C6
0472	D12->D15	AU-IC4, D1, D5, D6
0472	D16->D19	AU-IC5, E1, E5, E6
0476		AU-IC1; PC-B27, B28
0501	D0->D3	AU-IC12, A35, A29, A31, A30
0501	D4->D7	AU-IC11, B35, B29, B31, B30
0501	D8->D11	AU-IC10, C35, C29, C31, C30
0501	D12->D15	AU-IC9, D35, D29, D31, D30
0501	D16->D19	AU-IC8, E35, E29, E31, E30
0504	D0->D3	AU-IC12, A35, A29, A31, A30
0504	D4->D7	AU-IC11, B35, B29, B31, B30
0504	D8->D11	AU-IC10, C35, C29, C31, C30
0504	D12->D15	AU-IC9, D35, D29, D31, D30
0504	D16->D19	AU-IC8, E35, E29, E31, E30

(16) RI ADD AND CARRY TEST3

0513		AU-IC1, IC2, IC3, IC4, IC5; PC-B27, B28
0516		AU-IC12, IC11, IC10, IC9, IC8; PB-B27, B28

"A" ARITHMETIC UNIT DIAGNOSTIC

(1) D TO A TEST

0522	D0->D3	AU-A24, B24, C24, D24, E24
0522	D4->D7	AU-A25, B25, C25, D25, E25
0522	D8->D11	AU-A26, B26, C26, D26, E26
0522	D12->D15	AU-A27, B27, C27, D27, E27
0524		PC-B26, B28
0526		PC-B26, B28

(2) SLL A TEST

0532	D0->D3	AU-A24, B24, C24, D24, E24
0532	D4->D7	AU-A25, B25, C25, D25, E25
0532	D8->D11	AU-A26, B26, C26, D26, E26
0532	D12->D15	AU-A27, B27, C27, D27, E27
0534		PC-B26, B28
0536		PC-B26, B28

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S

(3) A+P->A, A-P->A TEST FOR P=+1B15

0542	D0->D3	AU-A24, B24, C24, D24, E24
0542	D4->D7	AU-A25, B25, C25, D25, E25
0542	D8->D11	AU-A26, B26, C26, D26, E26
0542	D12->D15	AU-A27, B27, C27, D27, E27
0550	D0->D3	AU-A24, B24, C24, D24, E24
0550	D4->D7	AU-A25, B25, C25, D25, E25
0550	D8->D11	AU-A26, B26, C26, D26, E26
0550	D12->D15	AU-A27, B27, C27, D27, E27

(4) A+P->A, A-P->A TEST FOR ALL BITS OF P

0564	D0->D3	AU-A24, B24, C24, D24, E24
0564	D4->D7	AU-A25, B25, C25, D25, E25
0564	D8->D11	AU-A26, B26, C26, D26, E26
0564	D12->D15	AU-A27, B27, C27, D27, E27
0575	D0->D3	AU-A24, B24, C24, D24, E24
0575	D4->D7	AU-A25, B25, C25, D25, E25
0575	D8->D11	AU-A26, B26, C26, D26, E26
0575	D12->D15	AU-A27, B27, C27, D27, E27

(5) MISCELLANEOUS TESTS

0577	D0->D3	AU-A24, B24, C24, D24, E24
0577	D4->D7	AU-A25, B25, C25, D25, E25
0577	D8->D11	AU-A26, B26, C26, D26, E26
0577	D12->D15	AU-A27, B27, C27, D27, E27
0601	D0->D3	AU-A24, B24, C24, D24, E24
0601	D4->D7	AU-A25, B25, C25, D25, E25
0601	D8->D11	AU-A26, B26, C26, D26, E26
0601	D12->D15	AU-A27, B27, C27, D27, E27
0603	D0->D3	AU-A24, B24, C24, D24, E24
0603	D4->D7	AU-A25, B25, C25, D25, E25
0603	D8->D11	AU-A26, B26, C26, D26, E26
0603	D12->D15	AU-A27, B27, C27, D27, E27
0605	D0->D3	AU-A24, B24, C24, D24, E24
0605	D4->D7	AU-A25, B25, C25, D25, E25
0605	D8->D11	AU-A26, B26, C26, D26, E26
0605	D12->D15	AU-A27, B27, C27, D27, E27
0607	D0->D3	AU-A24, B24, C24, D24, E24
0607	D4->D7	AU-A25, B25, C25, D25, E25
0607	D8->D11	AU-A26, B26, C26, D26, E26
0607	D12->D15	AU-A27, B27, C27, D27, E27
0611	D0->D3	AU-A24, B24, C24, D24, E24
0611	D4->D7	AU-A25, B25, C25, D25, E25
0611	D8->D11	AU-A26, B26, C26, D26, E26
0611	D12->D15	AU-A27, B27, C27, D27, E27
0614	D0->D3	AU-A24, A25
0614	D4->D7	AU-A25, A26
0614	D8->D11	AU-A26, A27
0614	D12->D15	AU-A27

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S
0617	D0->D3	AU-A24, B24, C24, D24, E24
0617	D4->D7	AU-A25, B25, C25, D25, E25
0617	D8->D11	AU-A26, B26, C26, D26, E26
0617	D12->D15	AU-A27, B27, C27, D27, E27
0622	D0->D3	AU-A24, B24, C24, D24, E24
0622	D4->D7	AU-A25, B25, C25, D25, E25
0622	D8->D11	AU-A26, B26, C26, D26, E26
0622	D12->D15	AU-A27, B27, C27, D27, E27
0625	D0->D3	AU-A24, B24, C24, D24, E24
0625	D4->D7	AU-A25, B25, C25, D25, E25
0625	D8->D11	AU-A26, B26, C26, D26, E26
0625	D12->D15	AU-A27, B27, C27, D27, E27
0630	D0->D3	AU-A24, B24, C24, D24, E24
0630	D4->D7	AU-A25, B25, C25, D25, E25
0630	D8->D11	AU-A26, B26, C26, D26, E26
0630	D12->D15	AU-A27, B27, C27, D27, E27

SCRATCH PAD DIAGNOSTIC TEST

0664	D0, 1	PC-A9, A10, A8
0664	D2->D5	PC-B9, B10, B8
0664	D6->D9	PC-C9, C10, C8
0664	D10->D13	PC-D9, D10, D8
0664	D14, 15	PC-A9, A10, A8
0761	D0->D1	PC-A9, A10, A8
0761	D2->D5	PC-B9, B10, B8
0761	D6->D9	PC-C9, C10, C8
0761	D10->D13	PC-D9, D10, D8
0761	D14->D15	PC-A9, A10, A8
0776		PC-E5, E10, C20, E19

DIAGNOSTIC FOR HORIZONTAL COUNTER

1011	AU-D8, E8, B22, B23, D22, E22
1024	AU-D8, E8, B22, B23, D22, E22
1031	AU-D8, E8, B22, B23, D22, E22
1037	AU-D8, E8, B22, B23, D22, E22
1044	AU-D8, E8, B22, B23, D22, E22

LOG/CHARACTER ROM TEST

1053	(LOG)	FAILURE AT EITHER ONE OF THESE TWO ADDRESSES
OR		INDICATE A MALFUNCTION OF THE LOG/ANTILOG OR
1062	(CHAR)	CHARACTER ROMS. CONTACT FACTORY FOR ADVICE ON REPAIR

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S

B ARITHMETIC UNIT TESTS

ZERO->BACC AND BACC+-1 TESTS

1067	D0,D1	PC-E7,E6,E5,E3
1067	D2->D5	PC-D7,D6,D5,D3
1067	D6->D9	PC-C7,C6,C5,C3
1070		PC-E6,B25,B28
1075	D0,D1	PC-E7,E6
1075	D2->D5	PC-D7,D6
1075	D6->D9	PC-C7,C6
1100		PC-E6,B25,B28
1105	D0,D1	PC-E7,E6
1105	D2->D5	PC-D7,D6
1105	D6->D9	PC-C7,C6
1107		PC-E6,B25,B26

BACC+-2I AND BACC+-2I+1 TESTS

1116	D0,D1	PC-B3,E3,E5
1116	D2,D3	PC-B3,E4,D5
1116	D4,D5	PC-B3,D3,D5
1116	D6,D7	PC-B3,D4,C5
1116	D8,D9	PC-B3,C3,C5
1123		PC-B3,C3,C5,C6
1133	D0,D1	PC-B3,E3,E5,E6
1133	D2,D3	PC-B3,E4,D5,D6
1133	D4,D5	PC-B3,D3,D5,D6
1133	D6,D7	PC-B3,D4,C5,C6
1133	D8,D9	PC-B3,C3,C5,C6
1141		PC-C5,D5,E5
1145		PC-B3,C3,C5,C6

B COUNTER, BSR, BSRREV TESTS

1155	D0,D1	PC-E2,E3
1155	D2,D3	PC-D1,D2,E4
1155	D4,D5	PC-D1,D2,D3
1155	D6,D7	PC-C1,C2,D4
1155	D8,D9	PC-C1,C2,C3
1160	D0,D1	PC-E3
1160	D2,D3	PC-E4
1160	D4,D5	PC-D3
1160	D6,D7	PC-D4
1160	D8,D9	PC-C3
1174		PC-E1,D1,C1,B26,B28
1200		PC-E1,D1,C1,B26,B28

W COUNTER TEST

1207		PC-B5,B6,B26,B28
1212		PC-B5,B6,B26,B28

ERROR ADDRESS	ERROR LOCATION	LIST OF PROBABLE IC'S

I COUNTER = 0 TEST

1217		PC-B4, B26, B28

2B TEST

1235	D0, D1	PC-B2, E3, E2, D2, C2
1235	D2, D3	PC-B2, E4, E2, D2, C2
1235	D4, D5	PC-B2, D3, E2, D2, C2
1235	D6, D7	PC-B2, D4, E2, D2, C2
1235	D8, D9	PC-B2, C3, E2, D2, C2

4B TEST

1245		PC-B1, E2, D2, C2

"RAM" DIAGNOSTIC TEST

1620 FAILURE AT THIS ADDRESS INDICATES A MALFUNCTION OF THE RANDOM ACCESS MEMORIES "RAM"

IN ORDER TO DETERMINE WHICH RAM HAS FAILED, A CODE MUST BE READ AS FOLLOWS:

1) DETERMINE WHICH BANK OF RAM'S HAS FAILED BY INSPECTING D15->D19 OF THE TOP LINE
   IF D15=1, THEN THE "B" AVERAGER RAM"S FAILED (B)
   IF D16=1, THEN THE PROCESSOR RAM"S FAILED (P)
   IF D17=1, THEN THE "A" AVERAGER RAM"S FAILED (A)
   IF D18=1, THEN THE INPUT BUFFER RAM'S FAILED (I)
   IF D19=1, THEN THE DISPLAY RAM'S FAILED (D)
   NOTE THE MNEMONIC "BPAID" INDICATING THE RAM BANK
2) DETERMINE WHICH RAM OF THE BANK HAS FAILED BY COMPARING THE FIRST 14 BITS (D0->D13) OF THE TOP TWO LINES. THE TOP LINE CONTAINS THE CORRECT ANSWER. NOTE D17->D19 OF THE SECOND LINE CONTAINS A TEST TAG INDICATING IN WHAT PARTICULAR TEST THE RAM FAILED AND IS ONLY NECESSARY TO BE UNDERSTOOD BY FACTORY TRAINED PERSONEL.
3) REPLACE THE BAD RAM AS PER THE FOLLOWING CHART
4) IF THERE IS INDICATION OF ONE OR MORE BAD RAM AND REPLACEMENT HAS NO EFFECT OR IF THE TOP TWO LINES ARE THE SAME: REPLACE THE FOLLOWING IC'S: PC-B11, C11, A8, B8, C8, D8, B7, E10, E11

BANK	BIT	IC
BAVG(B)	D0	PC-D26
BAVG(B)	D1	PC-D27
BAVG(B)	D2	PC-D28
BAVG(B)	D3	PC-D29
BAVG(B)	D4	PC-D30
BAVG(B)	D5	PC-D31
BAVG(B)	D6	PC-D32
BAVG(B)	D7	PC-D33
BAVG(B)	D8	PC-D34
BAVG(B)	D9	PC-D35
PROC(P)	D0	PC-A12
PROC(P)	D1	PC-A15
PROC(P)	D2	PC-B12
PROC(P)	D3	PC-B15
PROC(P)	D4	PC-C12
PROC(P)	D5	PC-C15
PROC(P)	D6	PC-D12
PROC(P)	D7	PC-D14
PROC(P)	D8	PC-D16
PROC(P)	D9	PC-E12
PROC(P)	D10	PC-E14
PROC(P)	D11	PC-E15
PROC(P)	D12	PC-E16
PROC(P)	D13	PC-E17
AAVG(A)	D0	PC-A13
AAVG(A)	D1	PC-A16
AAVG(A)	D2	PC-B13
AAVG(A)	D3	PC-B16
AAVG(A)	D4	PC-C13
AAVG(A)	D5	PC-C16
AAVG(A)	D6	PC-D13
AAVG(A)	D7	PC-D15
AAVG(A)	D8	PC-D17
AAVG(A)	D9	PC-E13
IB (I)	D0	AU-E9
IB (I)	D1	AU-D9
IB (I)	D2	AU-C9
IB (I)	D3	AU-B9
IB (I)	D4	AU-A9
IB (I)	D5	AU-A10
IB (I)	D6	AU-B10
IB (I)	D7	AU-B11
IB (I)	D8	AU-A11
IB (I)	D9	AU-A12
IB (I)	D10	AU-B12
IB (I)	D11	AU-A33
DISP(D)	D0	PC-A14
DISP(D)	D1	PC-A17
DISP(D)	D2	PC-B14
DISP(D)	D3	PC-B17
DISP(D)	D4	PC-C14
DISP(D)	D5	PC-C17
DISP(D)	D6	PC-E26
DISP(D)	D7	PC-E27
DISP(D)	D8	PC-E28
DISP(D)	D9	PC-E29
DISP(D)	D10	PC-E30
DISP(D)	D11	PC-E31

SECTION X

SCHEMATIC DIAGRAMS

This section of the instruction manual contains the interconnection diagrams, the schematics, and the wiring diagrams for the Model 444.

WARRANTY

Nicolet Scientific Corporation warrants each instrument manufactured by it to be free from defects in material and workmanship. Our liability under this warranty is limited to servicing or adjusting any instrument returned to the factory for that purpose and to replace any defective parts thereof. This warranty is effective for one year after delivery to the original purchaser when the instrument is returned, transportation charges prepaid by the original purchaser, and when upon examination it is disclosed to our satisfaction to be defective. If the fault has been caused by misuse or abnormal conditions of operation, normal service charges will prevail. In this case, an estimate will be submitted before the work is started. Warranty returns must first be authorized by Nicolet Scientific Corporation.

All equipment not manufactured by Nicolet Scientific Corporation is subject only to the warranty provided by the supplying manufacturer.

Nicolet Scientific Corporation reserves the right to make changes in the design of its instruments without incurring any obligation to make the same changes on equipment previously purchased.

CLAIM FOR DAMAGE IN SHIPMENT

The instrument should be tested as soon as it is received. If the instrument is damaged in any way, a claim should be filed with the carrier. A full report of the damage should be obtained by the claim agent, and this report should be forwarded to us. We will then advise you of the disposition to be made of the equipment and arrange for repair or replacement. Include model number, serial number, and purchase order number when referring to this instrument for any reason.

SHIPPING

If the unit fails to operate or any fault develops, the following steps should be taken:

1. Notify us, giving full details of the difficulty,

and include the model number and serial number of the equipment. On receipt of this information, we will give you service data or shipping instructions.

2. On receipt of shipping instructions, forward the instrument prepaid to Nicolet Scientific Corporation. If requested, an estimate of the charges will be made before the work begins, provided the instrument is not covered by the warranty.

3. If the instrument is to be shipped, it is imperative that it be properly packaged. Where possible, use the specially designed packaging material in which the unit was delivered.

This warranty is expressly in lieu of all other obligations or liabilities on the part of Nicolet Scientific Corporation, which neither assumes nor authorizes any person to assume for it any other liability in connection with the sale of its instruments.

MINI-UBIQUITOUS® FFT COMPUTING SPECTRUM ANALYZER

444A

the real-time problem solver

Designed specially to help understand the sources of noise or vibration and predict failure in:

- ships
- aircraft
- vehicles
- appliances
- machine tools
- nuclear reactors
- rotating machines

NICOLET SCIENTIFIC CORPORATION

NEW in the 444

A built-in microprocessor computes...

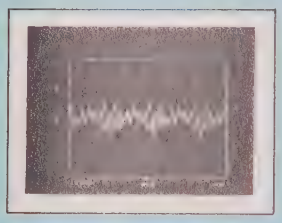
•ratio and difference of two stored spectra •1/3 or 1/1 octaves* •engineering unit calibration-linear or dB measurement, absolute or relative •total RMS readout •A-weighting

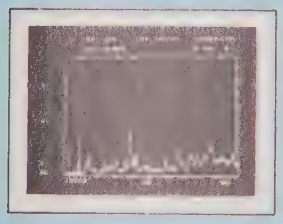
Plus...

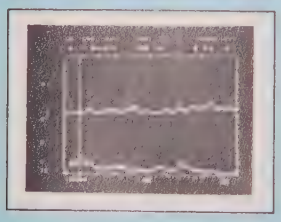
•100 kHz maximum range •report-ready annotated plots* •computer interface built-in* •built-in expansion of frequency detail* •mass storage add-on digital tape recorder*

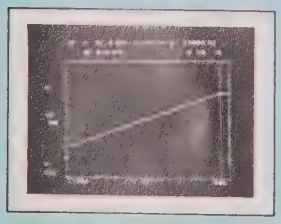
*Optional

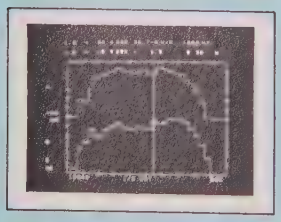
what's NEW in the 444

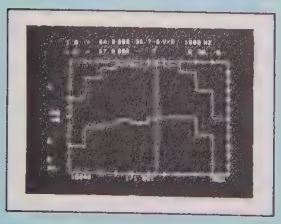


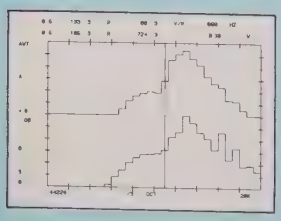












BUILT-IN MICROPROCESSOR COMPUTES THE SOLUTION TO 12 TYPICAL ANALYSIS PROBLEMS:

1. **Compares spectra** by calculating the ratio or difference of pairs of stored spectra, 400-line or 1/3 octave* . . . measures change by comparing previous digital tape records with current spectra**.
2. **Measures in linear engineering units** and maintains end-to-end calibration even with gain changes - also reads in V, V^2, dBV, or dBR (relative to reference).
3. **Calculates the calibration constant** in volts/engineering unit.
4. **Generates 1/3 or 1/1 octaves*** (30 1/3-octaves, 10 1/1-octaves); also relates each 400-line peak to its 1/3-octave band number.
5. **Reads total RMS** energy in analysis band as a digital number on the CRT.
6. **Reads peak voltage** of time displays.
7. **Calculates transmissibility** as the ratio of output to input power spectrum.
8. **Introduces A-weighting** characteristic for acoustic noise studies.
9. **Tests its own logic** and identifies the location of faulty components on a coded display*.
10. **Isolates individual signal sources** by subtracting out background.
11. **Equalizes for transducer irregularities** by dividing out transducer response.
12. **Reads ratio of amplitudes at the cursor** in dual display.

BASIC PERFORMANCE EXPANDED 11 WAYS

1. **Analyzes a wide variety of signals** with frequency ranges as high as 0-100 kHz and as low as 0-1 Hz (16 ranges).
2. **Stores** two 400-line averages in its dual memory . . . simultaneously stores two 1/3-octave spectra* in two additional memories.
3. **Provides visual comparisons** by dual displays . . . two averaged spectra or the instantaneous 400-line and averaged spectrum.
4. **Transfers and holds** on command (in B-memory) a momentary spectrum or averaged spectrum during a time-varying test (such as road passby) without stopping the processing of new data (in A-memory) . . . B = "Before", A = "After".
5. **Insures correct analysis of transients** by automatically switching to the appropriate flat weighting upon capture (in AUTO HOLD).
6. **Identifies records** by displaying operator-set ID number in annotation.
7. **Provides optimum resolution** with built-in frequency expansion (translation)* . . . origin of expanded band and width of band shown in annotation.
8. **Insures optimum display amplitude** through wide variation of gain and attenuation . . . up to X512 and ÷512 in 19 binary steps (lin), or ±50 dB in eleven 10-dB steps (log).
9. **Saves time** by plotting from B-memory while processing new data in A-memory.
10. **Produces report-ready plots** on a digital plotter*** including all annotation shown on CRT
11. **Simplifies post-processing** with built-in interface to terminals, calculators, and computers***.

*Built-in Option
**Using Model 144 Data Recorder
***Requires NSC Option -07

what can Spectrum Analysis do for You?

Spectrum analysis is the decomposition of a time varying signal into its sinewave frequency components. Many complex signals are difficult to understand as time functions; however, their spectra - the display of energy versus frequency - are relatively easy to understand. Spectrum analysis is a powerful technique for characterizing a signal, identifying its source and detecting its change. For example, gear meshing, rotational vibration, or bearing noise are recognized by associating mechanical periodicities with discrete frequencies in the spectrum.

HOW THIS BROCHURE CAN HELP YOU --

Complete annotation means understandable, report-ready records . . . . . Page 4

Total recording and interface . . . . . Page 5

ACOUSTICS APPLICATIONS: locating and reducing sources of noise . . . . . Page 6-8

TRANSIENT APPLICATIONS: capturing and analyzing impulses . . . . . Page 8

VIBRATION APPLICATIONS: diagnosis of the ills of rotating machines and other mechanisms . . . . . Page 9

Specifications . . . . . Page 10-11

Options and Accessories; rear panel controls and connections; self-test Option -05 . . . . . Rear Cover

WHY IS AN ALL-DIGITAL SPECTRUM ANALYZER BETTER?

★ **Absolute repeatability** results from digital stability and accuracy both in frequency and amplitude measurements without any calibration adjustments being required.

★ **Very wide dynamic range** is only possible by calculating the Fourier transform digitally to avoid the drift and non-linearity of analog circuitry. A wide dynamic range of 70-80 dB not only provides recognition of small components in the presence of large ones, but reduces the need for manual gain changes during a test.

★ **Simplified interface** to digital devices such as digital plotters, recorders, terminals, and computers allows integration of an all-digital analyzer into a digital data analysis system. (Also makes possible the loading of digital data directly into the analyzer from digital tape or a computer.)

★ **The accurate analysis of transients** without distortion can be achieved only by digital techniques.

★ **Where phase information is required,** the digital calculation of the Fourier transform provides "real" and "imaginary" components (available as digital outputs from the 444).

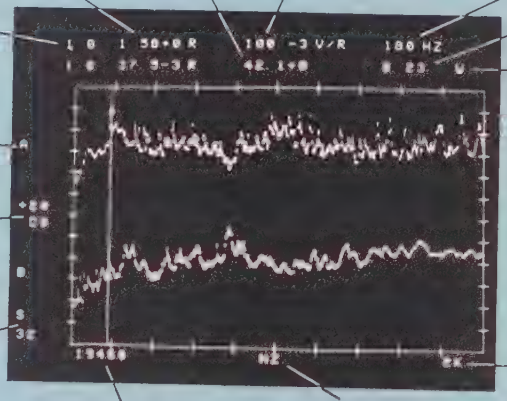
★ **Display and plotting of time data** is made possible by digital storage of the input time function.

complete annotation...

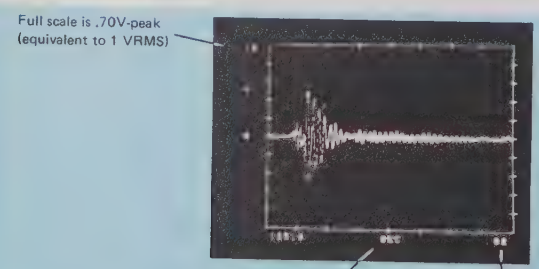
. . . means understandable, report-ready records. The 444 provides fully-annotated displays which include not only the spectrum or time data, but an electronic non-parallax scale perfectly aligned with the data, with the correct divisions marked on both axes to match logarithmic or linear scaling. The control settings of the Analyzer also appear, allowing at some later date complete understanding of the conditions under which the data was processed, **without** depending on the operator to keep time-consuming records. The unit even "remembers" the separate input amplitude sensitivities as they were set at the time spectra were averaged in each memory. Calculated data - total RMS, 1/3-octave band number, calibration constants, and the ratio of amplitudes at the cursor - also appear in the annotation. An ID number, set by the operator, using the Analyzer's front panel digital switch, appears for future identification. (If Expansion is used*, this becomes the origin frequency of the expanded band.) The total annotation can be preserved by photos, digital plots or digital tape records (see TOTAL RECORDING following).

DUAL AVERAGE SPECTRUM DISPLAY

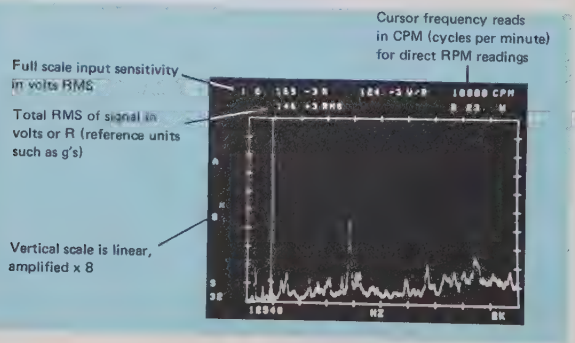
*Optional


Amplitude of A & B spectra at cursor in volts (V), volt squared (V2), dB relative to 1 volt (DBV), reference units (R), squared reference units (R2), or dB relative to 1 reference unit (DBR).
Ratio of A/B at cursor (Blank for single display)
Calibration in volts/engineering or "reference" unit (100-3" is read as 100 x 10^-3 i.e. 100 millivolts)
cursor frequency reading in HZ
Full scale input sensitivity range in volts RMS set at the time that A (upper) and B (lower) spectra were averaged and "remembered" by the unit.
1/3 octave band number at the cursor
W = weighting ON
U = unweighted for automatically captured transients
Spectra are averaged. Upper spectrum is stored in Memory A (active memory), lower in Memory B.
Vertical scale is logarithmic (dB) and display is amplified by 20 dB ("-20 dB" would be attenuated by 20 dB); for linear displays XN = multiplied by N, /N = divided by N
Averaging mode . . .
S = summation,
D = difference,
X = exponential, P-peak,
I = instant or un-averaged
32 = number of spectra averaged CON = continuous
I.D. number (or with -2 plug-in, expansion ON reads origin of translated band)
Horizontal scale . . .
HZ = lin. freq.
LOG HZ = log. freq.
1/3 OCT., 1/1 OCT. = octave scales
SEC = time
Frequency range (with -2 plug-in, expanson ON, reads width of built-in translated band)

TIME DISPLAY

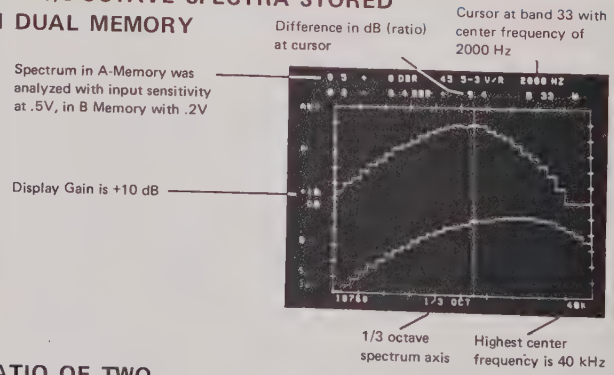

Full scale is .70V-peak (equivalent to 1 VRMS)
Time scale indicated by SEC for seconds
Time span is .02 sec, which is memory period on the 20 kHz range

SINGLE SPECTRUM DISPLAY

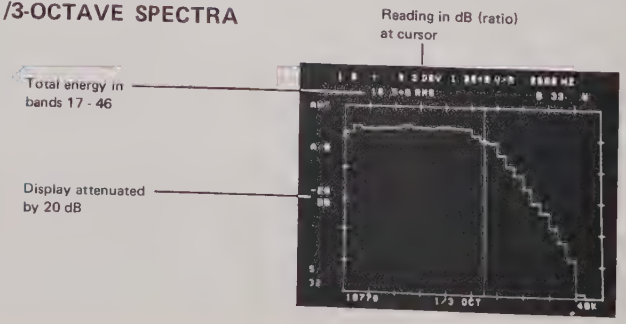

Cursor frequency reads in CPM (cycles per minute) for direct RPM readings
Full scale input sensitivity in volts RMS
Total RMS of signal in volts or R (reference units such as g's)
Vertical scale is linear, amplified x 8

MATHEMATICAL COMPARISON OF SPECTRA

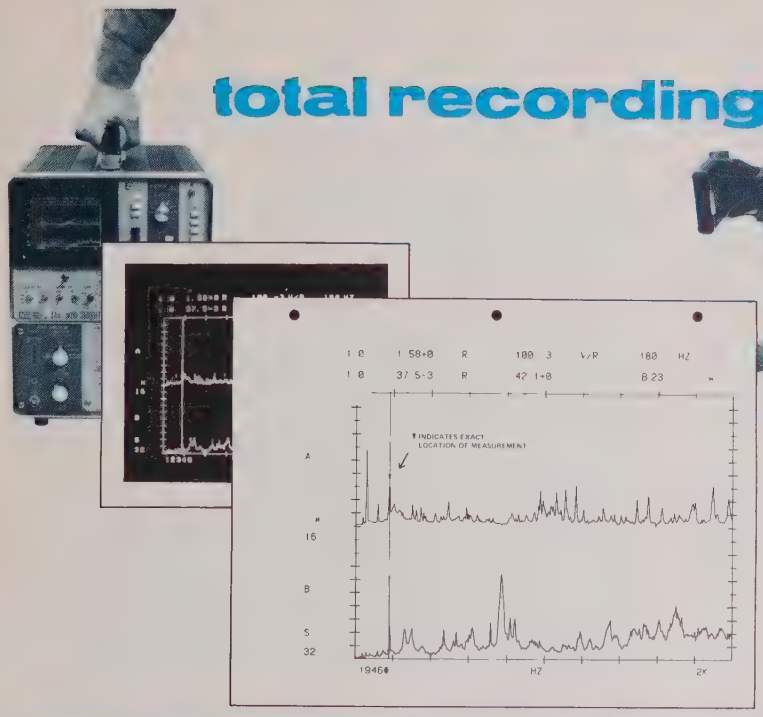
TWO 1/3-OCTAVE SPECTRA STORED IN DUAL MEMORY


Difference in dB (ratio) at cursor
Cursor at band 33 with center frequency of 2000 Hz
Spectrum in A-Memory was analyzed with input sensitivity at .5V, in B Memory with .2V
Display Gain is +10 dB
1/3 octave spectrum axis
Highest center frequency is 40 kHz

RATIO OF TWO 1/3-OCTAVE SPECTRA



total recording and interface

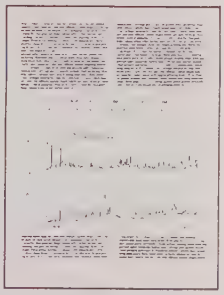


FAST PHOTOS

The 444 Analyzer's display is unique. Scales, control settings and calculated values are electronically written on the screen so that a photograph preserves a complete record. Option 61 is a convenient Polaroid camera adapted to fit on the Analyzer's bezel.

REPORT-READY PLOTS

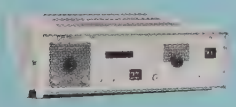
The annotated display of the 444 Analyzer can be **completely** reproduced on **any** paper by the use of a digital plotter (such as a Tektronix 4662) connected to the Analyzer via an RS232 interface (Option -07). In ½ to 1 minute the plotter produces all necessary lines and characters.



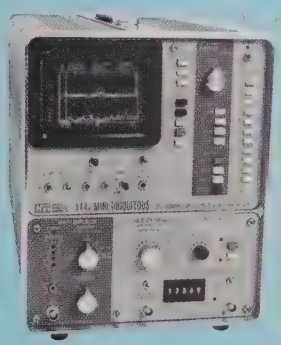
EXPANSION THRU INTERFACE WITH OPTIONS AND PERIPHERALS

The 444 Mini-Ubiquitous® interfaces with a wide variety of peripheral devices, which greatly extend its problem-solving capabilities. A digital plotter, for example, automatically provides a hardcopy plot of **all** the information on the 444 CRT display, including **all annotation and ID numbers in "report-ready" form.** Direct connection can be made to most computers or terminals which have an RS232 interface (Opt. -07). Interface can be made to a HP9800 series Digital Calculator (Opt. -07 (HP)). The total annotated display can be digitally recorded using the NSC Model 144 Data Recorder or photographed (Model 61 Recording Adapter camera). The spectrum alone (or time function stored in memory) can be recorded on an X-Y plotter such as NSC Model 131B. The 444 will also interface with many paper-tape punches (Opt. -07).

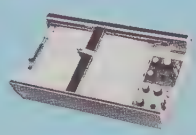
TACH



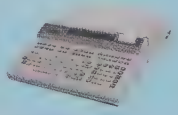
Signal Inputs typically from
- accelerometers
- velocity transducers
- displacement probes
- microphones
- hydrophones
- analog tape recorders
- digital computers, etc.



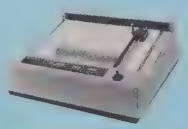
Computer Interface . . . Spectrum or time data transferred via an RS232 buss to any 16-bit computer. Computer can set most of Analyzer's controls. (Requires Opt. -07)



X-Y Plotter
(Example: NSC 131B) . . . Records spectra or time waveforms (without annotation) on 8" x 11" paper. During plotting the display remains on. Data in averager memory B can be plotted while new data is being averaged in memory A.



Calculator (Hewlett-Packard 9800 Series)
Special post-processing programs can be written by the operator. Calculator can set most of the Analyzer's controls. (Requires Opt. -07 (HP)



Digital Plotter
(Example: Tek 4662). . . Plots a complete display including scales and annotation in 30-60 sec. (Requires Opt. -07)

Expansion Plug-in
(-26 Option) . . .
Increases resolution and measurement accuracy by as much as 2000:1.

3-D Display
(NSC 66-2A/613) . . . A 3-D display of sequence of time-varying spectra produced on a large-screen storage-type oscilloscope. (Hard copy with Tek 4631)

Display Terminal
(Example: Tek 4010). . . provides large display (but not digital storage) as well as a terminal for computer interface. (Requires Opt. -07)

144 Digital Data Recorder . . . All information on the 444's screen can be stored digitally in a fraction of a second. Up to 1500 records can be stored on a small magnetic tape cartridge, and each record can be recalled by number. A recalled spectrum appears in the Analyzer as if it had just been obtained. Subsequent difference or ratio comparison with new data provides a powerful means of reading changes from "then" to "now" directly.

acoustics ... LOCATING AND REDUCING SOURCES OF NOISE

Spectrum analysis of the sound or vibration produced by a motor, fan, turbine or other complex machine provides a valuable means for identifying sources of noise, as the first step toward noise reduction. Three basic questions must be answered:

1. Does my device meet its noise specifications?
2. If not, where is the excessive noise coming from?
3. Having taken corrective action, did I actually reduce noise, and am I now in specification?

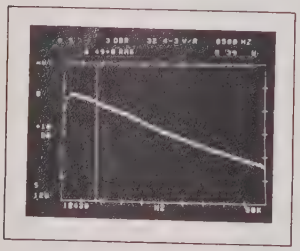
The 444 makes it simpler to answer these questions.

DO I MEET SPECIFICATION?

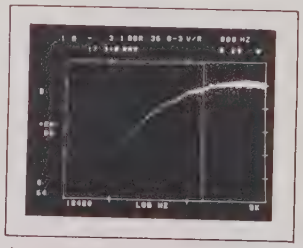
Most noise specifications are written in terms of overall sound level. In addition to its ability to read the amount of energy at each of many individual frequencies, the 444 also reads overall RMS level in any selected analysis range. If the input is from a microphone, the overall level is a measure of the total sound power generated by the source. If it exceeds pre-established levels of safety or desirability, some noise reduction may be necessary.

Readings Calibrated in Sound Pressure with A-Weighting

The 444 can be calibrated so that amplitudes can be read in units of sound pressure. A dB(A) reading, widely used in noise specifications, is a measure of RMS sound pressure level or force per unit area caused by a sound wave (at a microphone) as shaped by an A-weighting response curve. The zero reference for dB(A) measurements is 2×10^{-4} microbars which corresponds to the minimum sound pressure level detectable by the average human ear.

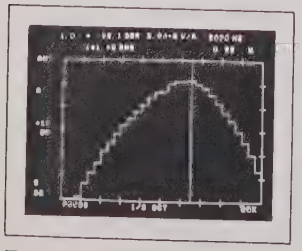


A-wt. noise spectrum shown in lin-log form on 50 kHz range

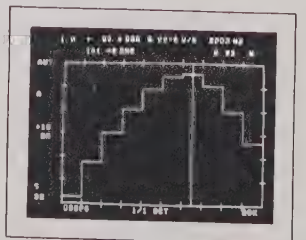


A-weighted noise spectrum on 5 kHz range, log-log form

Calibration of the 444 in "bandlimited dB(A)" requires a known sound input to a microphone connected to the unit, such as that produced by a standard sound level calibrator (typically an 80 - 100 dB(A) sinewave at 1000 Hz). Setting the cursor on the frequency peak (or on the appropriate 1/3 or 1/1 octave band with Opt. -03), R is adjusted until the cursor readings are in dB(A).



Typical A-weighted 1/3-octave spectrum of noise



Typical A-weighted 1/1-octave spectrum of noise

1/3 or 1/1-Octave Spectra

Some noise specifications are expressed in terms of octave or 1/3 octaves. These are bands of frequency which are relatively narrow at the low end of the range and wide at the high end, approximating the ear's ability to detect frequency differences. With option -03, the 444 can display 1/3 or 1/1-octave bands over a very wide range of almost 10 octaves from center frequencies of 6.3 Hz to 80,000 Hz in 5 ranges (band No. 8 to 49). These 1/3 or 1/1-octave bands are synthesized from 400-line spectra. Their center frequencies, bandwidths and effective rolloffs meet ANSI Standard Class III. The built-in A-weighting network can be switched in at the input so that the 1/3 or 1/1-octave spectra are modified by the A-weighting response curve.

360° Radiated Noise

For noise sources where a total 360° noise field measurement is desired, spectra (either narrowband, 1/3-octave or 1/1-octave) at individual microphone locations can be added together. A preset number of spectra at each location are averaged. If the microphone is moved 90° after each average, four such averages added together approximate a 360° total noise output.

Equalizing for the Microphone's Non-flat Response

In some cases the lack of uniform response of the microphone over the frequency range may cause measurement problems. With the 444, the resulting spectra can be equalized by the microphone response curve, if broadband noise is averaged and stored in Memory B. Subsequent spectra averaged in A Memory are then equalized by dividing the average in A by the stored response curve in B. The effect is to produce averaged spectra which appear to be processed through a microphone with a "flat" frequency response.

IF OUT OF SPEC, WHERE IS THE EXCESSIVE NOISE COMING FROM?

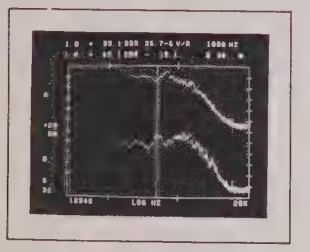
To determine the source of noise, a more precise measurement than overall RMS (or even 1/3 or 1/1-octave analysis) is usually required. The high resolution 400-line spectra of the 444 effectively separate discrete frequencies, which can then be associated with the source of noise, such as gear meshing, rotational unbalance, or fan blade passage.

Relate Narrowband Peaks with 1/3-Octave Bands

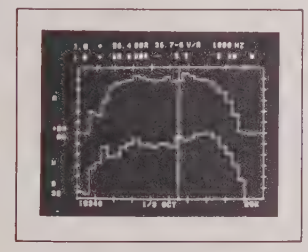
Excessively high 1/3 or 1/1-octave bands can be analyzed in more detail, using the 400-line spectrum analysis capabilities of the analyzer. A special feature of the 444 provides a readout of 1/3-octave band number in the annotation at the 400-line frequency element identified by the cursor. (This does not require -03 option.)

Flexible Display Formats for Comparisons

In order to compare 400-line narrowband spectra to 1/3-octave or octave spectra, the 444 provides a display of the 400-line spectra in log/log form (as well as linear/linear). The logarithmic frequency axis corresponds to the display of 1/3 or 1/1-octave spectra, where the successively wider bandwidths are displayed at equal increments on the frequency axis. Likewise amplitudes of 1/3 or 1/1-octave spectra are commonly produced in logarithmic form for dB or dB(A) measurements of power to cover a wide dynamic range.



Log-Log display format allows comparison with 1/3-octave spectra



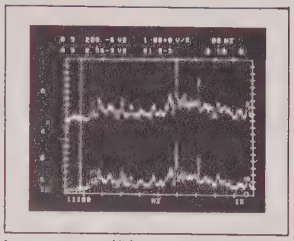
Dual 1/3-octave display provides a comparison of noise spectra before and after corrective action (showing a 9.5 dB improvement in Band 38)

Compare "Before" and "After" 1/3 or 1/1-Octave Spectra

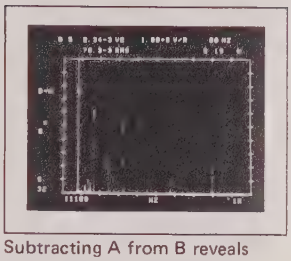
It is often useful to highlight the changes that have occurred from one test to another by displaying **only** the difference or ratio between spectra. With Option -03, two additional averager memories (total of four memories) are provided in the analyzer to store 1/3-octave spectra. As is the case with 400-line spectra, the spectra in the two additional storage memories can be subtracted or divided, reading difference or ratio directly. (Note that the "difference" between two spectra **in dB** is actually generated by taking the ratio of the two, displayed with a logarithmic amplitude scale.)

Isolating One Noise Source from Many

Isolating a source of noise in a noise environment (such as a factory) is necessary in order to identify the contribution of individual sources (such as a particular machine) to the overall noise. Since it is usually impractical to ask the plant manager to stop all production in order to measure the noise from this particular machine, a more practical technique must be employed.



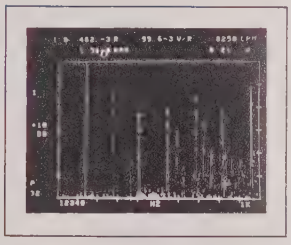
Lower trace (B) is averaged blower spectrum plus background; upper (A) is background only



Subtracting A from B reveals spectrum peaks of blower only (rotating at 80 Hz)

First, using the 444, the total noise of all machines is averaged and stored in Memory B, either as 400-line or 1/3 or 1/1-octave (if Option -03 is included). Second, the single machine under test only is turned off and another average obtained, which consists of the factory "background". If Memory A is subtracted from Memory B, the noise due to the single machine (total noise minus factory background) is then displayed. (The second average can be subtracted as it is averaged.)

Precision Measurement Improves Identification of Noise Sources



Harmonic markers illuminate frequency peaks which are multiples of the cursor frequency

The identification of specific noise sources is improved by use of the precise digital cursor. Specific peaks are accurately measured both in frequency and amplitude and thus related to mechanical motion. Since complex machines produce a multitude of frequency peaks, it is important to identify which ones are caused by each specific mechanisms. Since these mechanisms usually produce frequencies which are harmonically related, the analyzer's harmonic markers aid greatly in this identification. The harmonic marker dots illuminate only those frequency peaks which are multiples of the fundamental frequency selected by the cursor.

Averaging Improves Repeatability

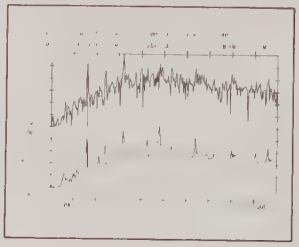
In general, noise sources include a multiplicity of frequencies, many of them beating together to produce a "noise-like" or random signal. This is particularly true for turbulent noise, such as that produced by a fan or pump. The spectrum of such a random signal is likewise random and therefore not repeatable from instant to instant. Spectrum power averaging produces the mean power spectrum of many instantaneous spectra. The wide variation of amplitudes at each frequency in the instantaneous random spectrum is reduced by averaging. The longer the averaging, the closer the averaged spectra will approach the "true" mean. Since the variance is reduced, the repeatability from one average to another is increased allowing meaningful measurements.*

*Note that the true mean cannot be obtained with less than an **infinite** number of spectra in the average. Since this is not practical, there is always some variance and it is well to refer to the averaged spectrum as the "estimate" of the true mean.

Continued on next page . . .

acoustics (cont'd)...

The 444 provides a choice of averaging modes for either 400-line spectra or 1/3 or 1/1-octave spectra (with Option -03). Summation averaging is used to average a preset number of power spectra, where the input signal statistics are relatively constant. This number can be set from 1 to 512 in binary steps. Difference averaging subtracts a preset number of power spectra from a previous average. (Although "negative" amplitudes are not displayed, their digital number is retained for accurate calculation.) Exponential averaging provides a changing average, where the character of the input signal is likewise changing in time. Peak is not truly an "averaging" mode, but rather stores a profile of the highest amplitudes at each frequency.

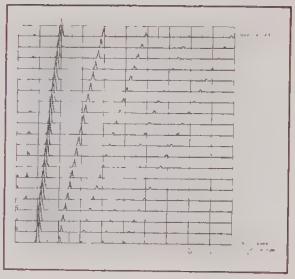


The average of 128 spectra (B) reveals peaks, which are not visible in the instantaneous spectra (I).

Passby, Flyby, and Startup Tests Simplified

Where a succession of spectra represents **changing** data, as in an automobile passby test or a motor startup, summation averaging is not meaningful. Instead, each spectrum or the successive averages of a few spectra are observed and recorded.

It is sometimes necessary to capture one spectrum when the **overall RMS** noise is loudest. In the 444 the instantaneous total RMS is displayed. In order to hold the spectrum with the largest total energy, the operator sets averaging to EXPON and watches the total RMS reading. When it appears to have peaked, he pushes the TRANSFER A→B memory button, storing the momentary average (or instant spectrum if N is set to "1"). With Model 144 Digital Data Recorder a succession of exponentially averaged spectra produced by the 444 can be digitally stored at a rate of approximately one per second. A playback from the Digital Recorder through the 444 can be made to automatically produce a "stacked plot", showing successive spectra one under the other and revealing the spectrum changes that occurred during the test.



Automatically generated stack-plot of motor coasting down in speed

DID I ACTUALLY REDUCE THE NOISE?

Comparison of spectra "before" and "after" corrective action reveals the changes that have occurred. If "before" spectra have been recorded on a 144 Digital Data Recorder, they can be played back and stored in one memory of the 444, while "after" spectra are stored in the other. A visual comparison or the calculation of the difference or ratio of the two reveals just how much improvement was realized. Comparisons can be made in 400-line spectra or 1/3 or 1/1-octave spectra (if Opt. -03 is included). Since the overall RMS level also may have been recorded in the annotation in the 144 Recorder (for single displays), its playback into the 444 and subsequent display on the 444 screen serves as a reference number for evaluating overall sound level improvements.

transients... CAPTURING AND ANALYZING IMPULSES

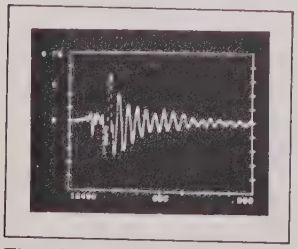
Automatic Capture

Transients may be manually captured by pushing HOLD, or automatically captured by first pushing the AUTO ARM button. The next transient above a preset trigger level initiates capture. The trigger point on the transient waveform is positioned so that 128 samples **prior** to trigger can be observed.

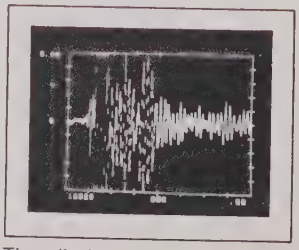
The length of time held by the input memory is set using the frequency range switch. Memory periods may be set as short as four msec (100-kHz range) to as long as 400 seconds (1-Hz range). The Analyzer's memory holds 1024 samples.

Verify Transients in the Time Domain

The contents of the input memory and therefore the waveform of the captured transient can be viewed. This allows the operator to verify that the correct transient has been captured and, more important, that it has not exceeded the dynamic range of the Analyzer, shown as the graticule limits.



Time display of transient captured on the 20 kHz range



Time display of transient captured showing overload

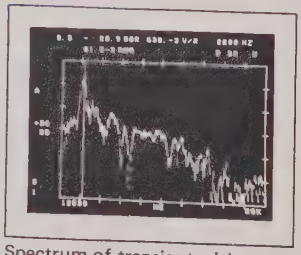
Use As Transient Recorder

Because the waveform can be held, viewed and subsequently plotted, the 444 Analyzer also serves as a "transient recorder" with a maximum sampling rate of 256,000/sec and 12-bit A/D conversion. Unlike commercial transient recorders, however, the bandwidth of the input and the sampling process are always **matched.** This prevents aliasing or "too low" sampling, which may produce erroneous information.

The waveform of the transient may be photographed, plotted on an X-Y plotter or produced along with all of the annotation on a digital plotter such as a Tektronix 4662.

Analyze and Store in the Frequency Domain

Once the transient has been captured, its frequency spectrum can be produced. If the data has been captured automatically, the weighting function normally superimposed on the data is automatically removed, preventing errors under normal conditions. The operator may also manually introduce or remove weighting.



Spectrum of transient with cursor on fundamental frequency (spectrum was transferred to averager memory A for storage)

Average to Increase Repeatability

A succession of transients may vary slightly from one to the other. In order to derive the mean spectrum information, it is necessary to average their spectra. This can be done in three different ways - manually, semi-automatically or automatically.

It is generally accepted that excessive machine vibration is a sign of poor operation and impending failure. It remains to be determined, however:

"What is excessive?"
"Is less than perfect operation a cause for concern?"
"How soon will failure occur?"

The 444 is **specifically** designed to help answer these questions by simplifying the identification, measurement, and recording of the component frequencies in the machine's vibration signature and comparing signatures mathematically.

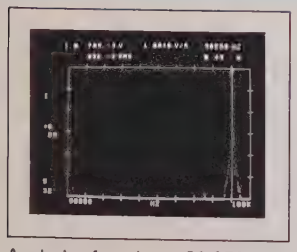
Calibrate to Read in Engineering Units

Amplitude calibration in engineering units familiar to the user provides measurements which relate directly to the type of data being analyzed . . . acceleration, velocity, displacement, temperature, flow, etc. Because the 444's readings can be set to any linear or logarithmic (dB) number, **the Analyzer can be calibrated in any desired units of measure.** At the time of calibration, the setting of the front panel input sensitivity switch is "remembered" by the unit, so that subsequent changes of sensitivity are taken into account in maintaining calibration. The calibration is therefore "end-to-end." If the spectrum is calibrated in engineering units, the overall RMS level read in the annotation is in these same units.

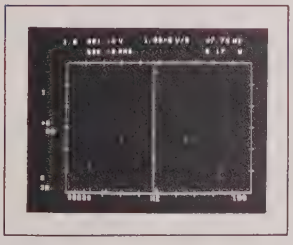
If a calibration signal of known amplitude is available, the reading of its amplitude (as measured with the cursor) is set to the known number of engineering units (referred to as "reference" or R units).

If a transducer of known sensitivity is used, calibration is equally simple. The transducer sensitivity in volts/reference unit (V/R) appears in the annotation and may be adjusted to the correct reading.

Process to Enhance Significant Detail



Analysis of carrier at 90,250 on 100 kHz range (200 Hz resolution) fails to show sidebands.

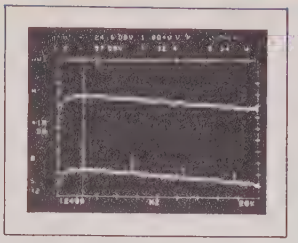


Expansion from 90,230 - 90,330 Hz with resolution of .25 Hz reveals sidebands

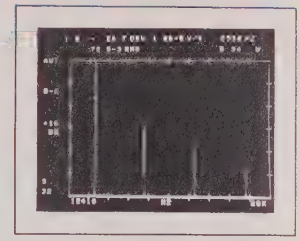
The use of Expansion (-2 plug-in opt.) increases the Analyzer's ability to separate closely-spaced peaks, measure frequency accurately, and provide a greater ratio between periodic signals and broadband "noise".

The built-in averaging capability in the 444 further increases the detectability and measurement repeatability of periodic frequencies in noise. In SUM MODE, fluctuations and noise are averaged out by the addition of a preset number of instantaneous power spectra, producing a **true power average.**

The unique difference (DIFF) mode allows removal of background or other unwanted spectra by subtracting a second set of power spectra from a previous average. In this way, even the low background of the Analyzer itself can be subtracted out .



Lower trace is filtered noise mixed with a sinewave, upper trace is the averaged background noise



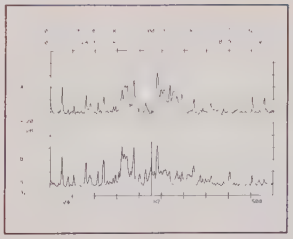
Difference between two traces removes background; low level signal at 595 Hz now evident

Motor startups, or other changing phenomena, are followed by using the exponential (EXPON) averaging mode. This provides a "moving" average of changing character, but with some of the randomness averaged out. The PEAK mode stores the profile of the highest amplitude that occurs at each frequency during a test, such as motor run-up or run-down.

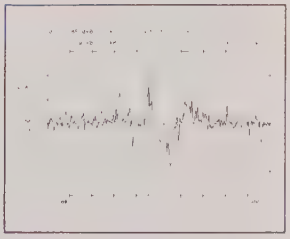
Flexibility Matches a Variety of Problems

Flexibility in frequency and amplitude ranges matches the 444 to each specific problem. Ranges from 0 - 1 Hz (0 - 60 RPM) to 0 - 100,000 kHz (0 - 6,000,000 RPM) allow optimum analysis at any speed. The 444 provides an alternate display of frequency in terms of rotational orders, rather than Hz or CPM. By normalizing to a tachometer, speed changes do not shift spectrum peaks related to rotation and comparison of signatures at various speeds is simplified. (Option 24C-07 provides an adjustment of the number of orders displayed.)

Compare Present Signatures with Past Ones



"Today's" vibration spectrum B shows increased peak amplitudes compared to past spectrum.



The ratio of B (today) to A (past) spectra shows an increase at 227.5 Hz, (indicated by the cursor).

The 444 contains two memories for simultaneous storage of past and present spectra. In combination with a Model 144 Data Recorder, which provides fast access to thousands of records, one memory is used to hold a past signature of the machine ("as new", after overhaul, etc.). All of the annotation is recalled with the spectrum, completely describing the calibration and control settings at the moment the data was originally processed. Three different numbers affixed to the record simplify search and identification.

In dual display the ratio of corresponding peaks, identified by the cursor, is calculated and read in the annotation. **Subtracting** the spectra displays the amplitude differences directly in the engineering units or volts (or V^2) at each frequency. **Dividing** one by the other produces their ratio, which allows readout of proportionate increase or decrease.

specifications . . .

(standard model is 444A-16 - see options and accessories for added capabilities)

DISPLAY (on built-in CRT)

Data: Repetitive readout of one of the following:

- Time function, continuous or captured
- Instantaneous spectrum of time functions
- Averaged power spectrum A or B
- Instantaneous spectrum *and* averaged power spectrum A (dual display)
- Instantaneous spectrum *and* averaged power spectrum B (dual display)
- Averaged power spectrum A *and* averaged power spectrum B (dual display)
- Averaged power spectrum A *plus* averaged power spectrum B
- Comparison by displaying difference - Averaged power spectrum A *minus* averaged power spectrum B, or B *minus* A
- Comparison by displaying ratio - Averaged power spectrum A *divided by* averaged power spectrum B, or B *divided by* A

Electronic Graticule: Non-parallax rectangular graticule is generated; 10 marks on frequency axis for linear and 2 marks for log (at 1 and 2 decades below full scale); for single displays, 10 marks on amplitude axis for linear and 6 marks for log (at 10 dB intervals); for dual displays, twice as many amplitude marks are produced; for time, eight marks for horizontal and ±5 marks around zero center for vertical, top and bottom correspond to input amplitude full scale; rear panel switch removes graticule.

Annotation: For frequency displays, letters and numbers indicate input sensitivity in VRMS, frequency range, type of data, averaging mode, number of spectra averaged, data weighting, display gain/attenuation, A-weighting on/off, mathematical calculation between averages, and 4-digit I.D. number; for time displays, full-scale input amplitude read as volts (zero to peak); horizontal time scale indicated by "SEC" and frequency scale by "HZ"; indicates origin frequency of expanded range in place of ID number (for 444-26 units) when in expanded mode; rear panel switch removes annotation.

Overall RMS Level: Shown on CRT for single spectrum displays (when cursor is on) for 400-line or 1/3 or 1/1-octave (-03 opt.).

Measurement Cursor: Cursor line moved left or right continuously or by single resolution element; intensified dot where line intersects spectrum (if intersection is within graticule); can be turned off.

Amplitude at Cursor: Referenced to 1 VRMS and read in units of V, V^2, or dB with respect to 1V (dBV); or read in *engineering units* directly by reference to any voltage from 1.00×10^{-9} to 999×10^{9} set by front panel GAIN controls; for dual spectra displays amplitudes of each and their ratio at cursor location.

Frequency at Cursor: For 400-line spectra, frequency reads in Hz (cycles/sec) or CPM (cycles/minute); also reads 1/3-octave band number if within bands 8 to 49 or approximately 6 Hz to 94 kHz (-03 option *not* required); in ORDERS (external sampling), reads % FS; reads in annotation only when cursor is on.

(Subject to change without notice)

Harmonic Marks: Additional intensified dots illuminate multiples of cursor setting on 400-line spectra; number of dots indicate harmonic number up to a maximum of 5 dots.

Display Scales: Lin or log, frequency or amplitude of spectrum

Display Gain: Linear - gain of 512 ("X512") to attenuation of 512 ("/512") in binary steps; log - gain of +50 dB to attenuation of -50 dB in 10 dB steps; set by front panel GAIN control.

ANALYSIS CHARACTERISTICS (400-Line)

Frequency Ranges: 1, 2, 5, 10, 20, 50, 100, 200, 500, 1,000, 2,000, 5,000, 10,000, 20,000, 50,000 and 100,000 Hz with built-in anti-aliasing filters (1, 2, 5 Hz ranges filtered with 10 Hz filter).

Number of Resolution Elements: 400 per spectrum (generated from 1024 input time samples); nominal bandwidth, β, is 1/400 frequency range; noise bandwidth is 1.5β (1.0β when data automatically captured or armed).

Amplitude Linearity: ±0.1 dB or ±.05% of FS to 66 dB below FS, whichever is greater (no adjustment necessary).

Frequency Accuracy and Stability: .01 percent of full scale without warmup (no adjustment necessary).

Minimum Detectable Signal: –70 dB typical, –75 dB with background subtraction.

Two-Tone Dynamic Range: Typically better than 66 dB.

Intermodulation Distortion: –70 dB typical.

Amplitude Measurement Stability: ±.1 dB from 10° C to 50° C (50° F to 120° F).

Expansion Plug-In (Option -26): Built-in translator provides one analyzer band of 10 Hz, 50 Hz, 100 Hz, 500 Hz, 1 kHz, 2 kHz, 10 kHz or 20 kHz wide positioned in 10 Hz steps to 100 kHz; extra plug-in cards provide additional ranges (except for 10 Hz which requires modification of basic unit); origin frequency indicated on display (in place of I.D. number).

TRANSIENT DATA

Data Hold: Manual HOLD/REL button holds data in input memory or allows new data to enter; AUTO ARM (or remote signal) allows next signal over preset level to automatically actuate hold; in auto-hold, 1/8 of memory period *before* trigger can be viewed; polarity and amplitude of auto-hold triggering selected as ±1/16, ±1/8, ±1/4, or ±1/2 of full input amplitude, lights indicate data being held or unit is armed; one spectrum of held data can be transferred to averager A memory by pushing START A after capture.

Viewing Held Data: Time signal can be displayed and plotted; in automatic hold, trigger level indicated by brightened dot on CRT. (Time not displayed when in 1/3-oct. or 1/1-oct. mode with Option -03.)

Data Weighting: Weighting removed automatically in ARMED or when data captured (in AUTO position of rear panel switch), or can be manually controlled using rear panel switch.

Memory Period: Length of data stored in the input memory in seconds is 400/frequency range (Hz).

Automatic Transient Averaging: Rear panel jumper provides automatic arm, capture and averaging of a succession of input transients (not valid for 1/3 or 1/1-octave mode with Option -03).

INPUT CHARACTERISTICS

Input Impedance: 100 kilohms

Input Coupling: AC (-3 dB at less than 0.5 Hz), DC

Test Signal: Sinewave at 64 percent of display, replacing input signal

Input Amplitude Sensitivity: (Volts RMS full scale) 100 mv (-20 dB), 200 mv, 500 mv, 1V (0 dB), 2V, 5V, and 10V (+20 dB).

Input Amplitude Monitor: Lights indicate peak signal levels - OVERLOAD, -6 dB (greater than 1/2 full scale), -12 dB (between 1/4 and 1/2 FS), -18 dB (between 1/8 and 1/4 FS), and -24 dB (between 1/16 and 1/8 FS); all lights below the signal level illuminated (in overload, all lights are on).

Input Sampling: 12-bit A/D conversion at 2.56 times maximum frequency of range selected on internal sampling (FREQ); external sampling input (ORDERS) sets frequency coverage at 1/2.56 of sampling rate. (Display in orders of rotation requires 2.56 pulses/revolution/order.)

Input Filters: Lowpass anti-aliasing filters matched to each range with an initial rolloff of 120 dB/octave (7-pole elliptic); 10-Hz filter on 1, 2 and 5 Hz ranges; frequency response ±0.5 dB (except ±1.0 dB on 100 kHz range).

Digital Input: External digital data can be loaded in 2's complement form directly into memory (through rear connector).

A-Weighting: Synthesized A-weighting can be applied to ranges of 5K and above for 400-line analysis, or any 1/3 and 1/1-octave ranges (with Option -03).

AVERAGING

Modes:

SUM - power spectra are added (true power averaging)

DIFF - power spectra are subtracted linearly from the previous average (negative amplitudes clipped at display bottom but *retained in memory*).

EXPON - average changes in time as the signal spectrum changes (N sets exponential time constant); operation equivalent to a "leaking integrator".

PEAK - stores maximum spectrum amplitude at each frequency location during an averaging cycle, producing a profile of maxima.

Averaging Control:

STOP A - manual stop of averaging in A memory

START A - resets number of measurements count, erases A averager memory (unless in DIFF mode), and starts averaging in A memory.

CONT (Continue) A - starts averaging a A memory *without* erase; in SUM, DIFF, or PEAK mode, if actual number of spectra averaged is equal to or greater than setting of N, resets count.

TRANSFER A→B - transfers the contents of memory A to memory B, either during averaging in A memory or after averaging has stopped. (400-line, or 1/3-octave with Option -03).

Number of Averager Memories: Two for 400-line spectra (plus 2 for 1/3-octave spectra with Option -03; 1/1-octave display derived from 1/3 octaves).

Number of Spectra Averaged - N: Determines time of averaging or time constant of exponential averaging; set from 1 to 512 in binary steps; in CONT, averaging continues until STOP button is pushed.

IN-PROCESS Light: Flashes to indicate averaging is taking place; flashes in EXPON until N is reached, then is lit continuously.

1/3 or 1/1-OCTAVE ANALYSIS (Option -03)

Range Setting	Center Freq. Range (Hz)	(ANSI Std. 1/3-oct. band numbers)	Time Per Anal. (sec)
1/3-oct.			
5k	6.3 - 5,000	(Band 8 - 37)	2.4
10k	12.5 - 10,000	(Band 11 - 40)	1.2
20k	25 - 20,000	(Band 14 - 43) Type E	.8
50k	50 - 40,000	(Band 17 - 46)	.8
100k	100 - 80,000	(Band 20 - 49)	.8
1/1-oct.			
5k	8.0 - 4,000	(Band 9 - 36)	2.4
10k	16.0 - 8,000	(Band 12 - 39)	1.2
20k	31.5 - 16,000	(Band 15 - 42) Type E	.8
50k	63 - 31,500	(Band 18 - 45)	.8
100k	125 - 63,000	(Band 21 - 48)	.8

Characteristics: 1/3-octaves synthesized from narrow-band spectra; center frequencies, bandwidths, and effective rolloffs meet ANSI Class III standards; 1/1-octaves synthesized from 1/3-octave spectra.

Cursor Reading: Center frequency in Hz, 1/3-oct. band number and amplitude; ratio at cursor in dual displays.

Dual Memories: Two additional averager memories store 1/3-octave spectra.

OUTPUT CHARACTERISTICS

CRT Outputs: X, Y, Z outputs for external annotated display

X-Y Plotting (without interruption of display): X, Y and pen lift outputs for analog X-Y plotter; plots single spectrum or time function; ORIGIN (zero volts) and FULL SCALE buttons position pen at lower left and upper right of scale; for 400-line log frequency, ORIGIN is first resolution element; in AT CURS, X and Y outputs follow cursor horiz. and vert. position; during PLOT, cursor follows pen while full display is simultaneously produced on CRT; can plot averaged spectra in B memory while averaging is taking place in A.

Store CRT: Slows display to match storage oscilloscope (e.g. Tek 613); output for annotated plots using a Tek 4662 digital plotter or annotated display on a Tek 4000 series CRT terminals (requires Option -07 RS232 interface); internal control selects one of the following when STORE CRT button is pushed: (1) record on Model 144 Digital Tape, (2) start paper tape read, (3) output ASCII data for paper tape punch (control settings and amplitude spectrum or time, control settings and real/imaginary, or control settings and real/imaginary *and* spectrum or time), (4) output ASCII on RS232 (requires Option -07).

Digital Input/Output: 16-bit parallel with 4-bit ID code.

Remote Control and Sense: Can sense all front panel switches and amplitude lights; can control all front panel switches; 8-bit parallel ASCII output (requires Option -07HP for HP9800 series calculators, or Option -07 for RS232 ASCII interface).

MISCELLANEOUS

Weight: 19 kgm (42 pounds) nominal with typical plug-in.

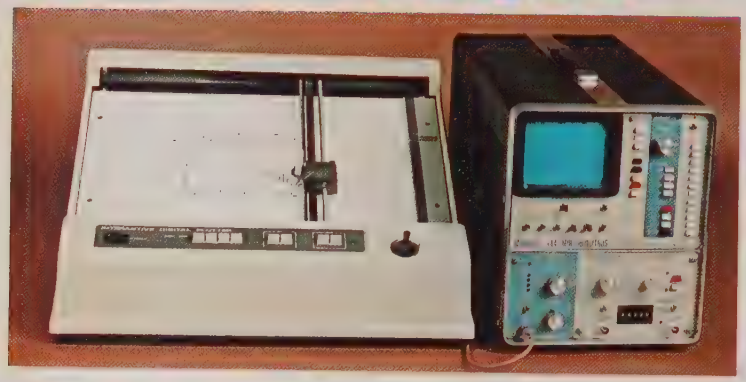
Power: 90 – 130 volts or 180 – 260 volts, 48–66 Hz, nominal 150 watts.

Size: 32.6 cm (12-7/8 inches) high including feet and handle, 25.3 cm (10 inches) wide, 51.9 cm (20-7/16 inches) long including maximum front and rear protrusions.

Storage Temperature: -55°C to +85°C (-67°F to +185°F)

Operating Temperature: 0°C to 55°C (+32°F to +130°F)

444 mini-ubiquitous® fft computing spectrum analyzer



Accessories:

Model 99F Transit Case
Model 21 Vibration Input Adapter
Model 24C-07 Spectrum Tracking Adapter
Model 30C Range Translation Unit
Model 51 Transducer Kit (Accelerometer)
Model 61 Recording Adapter (Polaroid Camera)
Model DO-613 Large Screen Storage Display Unit
Model 66-2A/DO-613 3-D Display
Model 134A Digital Plotter
Model 131B X-Y Plotter
Model 144 Data Recorder (digital cartridge recording)

Options:

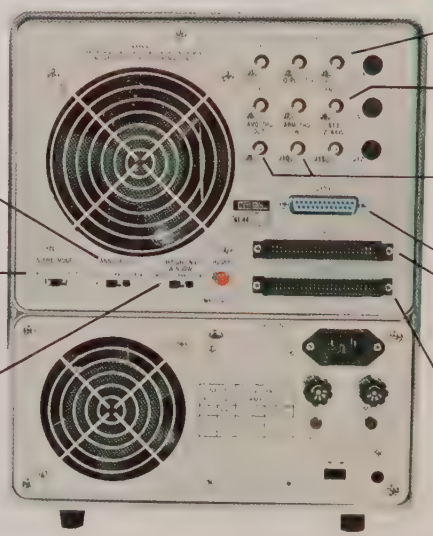
26( ) _____ Expander Plug-in (specify range)
01 _____ Male plug for rear connection
02 _____ Rack mounting adapter (14" height)
03 _____ 1/3, 1/1-octave analysis
04 ( ) Range cards for -26 Plug-in (specify range)
05 _____ Self-test logic diagnostics
06 _____ Remote control and sensing
07 _____ RS232 Interface
07HP Interface (for HP9800 Series Calculators)

OPTION -05 (SELF-TEST LOGIC DIAGNOSTICS)

The most difficult section to service of a digital instrument, such as the MINI-UBIQUITOUS®, is the digital logic. Option -05 built-in self-test logic routines simplify service by personnel who are not specifically trained on the unit, and in many cases allow location of faulty I.C.'s in the field.

The operator initiates a test routine by pushing a combination of front panel buttons on the Analyzer. A 3-line code pattern (similar to the photo) appears if some logic operation in the arithmetic sections or main memory is at fault. (A "code book" indicates which I.C. or group of I.C.'s.)

Since it is possible that logic faults in the Analyzer may prevent a display on the CRT, Option -05 does **not** use the normal program steps associated with display (although it does assume a normally operating display section).



Annotation can be partially or fully removed

Store mode defines the device actuated by the front panel STORE CRT button (CRT is storage type; PLOT is for digital plotter; AUX is for other peripherals).

Hanning or flat weighting can be manually selected. In AUTO, the normal Hanning weighting is changed to flat automatically when a transient is captured.

Connections for large screen or other auxilliary display

Analog X-Y plotter connections

A jumper from J9 to J10 re-arms the the auto-transient capture after each spectrum for automatic averaging of transient spectra.

For RS232 interface connection with Opt. -07.

High speed I/O connection for 144 Data Recorder and other peripherals

NICOLET SCIENTIFIC CORPORATION

NICOLET SCIENTIFIC CORPORATION / 245 Livingston St., Northvale, New Jersey 07647 (201) 767-7100
(formerly Federal Scientific Corp.) TWX: 710 991 9619

NICOLET INSTRUMENTS LTD./80A Emscote Rd., Warwick, Warwickshire, England/Te.(0926) 44451 and 44452/Telex: 851311135
NICOLET INSTRUMENT GMBH/Frankfurter Strasse 121, 6050 Offenbach am Main, W. Germany/Te. 0611/812075/Telex: 8414185411
NICOLET INSTRUMENT CANADA LTD./23-1616 Matheson Blvd., Mississauga, Ont. L4W 1R9/Te.(416) 625-3901/Telex: 06-960126

PRINTED IN U.S.

MACHINE DESIGN
A PENTON PUBLICATION □ JUNE 10, 1976

The hidden message in Mechanical Vibration

THE 'HIDDEN MESSAGE'

GEORGE F. LANG
Manager Application Engineering
Nicolet Scientific Corp.

When a part vibrates, it's trying to tell you something. You can get the message—and put an end to such mechanical miseries as noise and excessive dynamic stress—if you know how to "listen" with an electronic spectrum analyzer.

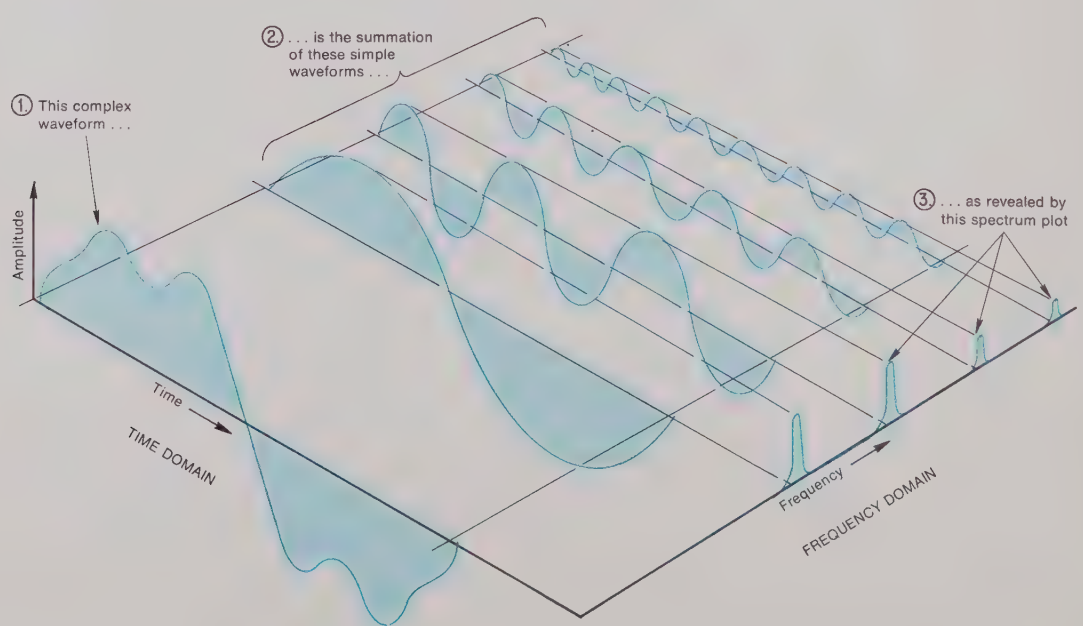
VIBRATION usually can be controlled or eliminated if the driving force can be identified.

Sometimes the source is obvious. For example, if a vehicle structure has severe vibrations of 1,000 Hz at 30 mph, and if the engine speed at 30 mph is 1,000 rpm, there's a good chance that the vibration is driven by engine imbalance rather than, say, suspension dynamics.

In most cases, however, the

What Is Spectrum Analysis?

Vibration in a typical vehicle or machine is generally the net effect of several driving forces. The total effect conceals the individual components and makes them difficult to identify. Spectrum analysis is a method for resolving this complex vibration back into its basic constituents. For example, a conventional vibration trace is a time-domain view or time-history as seen along an amplitude vs. time axis. Spectrum analysis "looks inside" this amplitude-time plot and shows it in the frequency domain as a plot of amplitude vs frequency.


② . . . is the summation of these simple waveforms . . .
① This complex waveform . . .
③ . . . as revealed by this spectrum plot
Amplitude
Time
TIME DOMAIN
Frequency
FREQUENCY DOMAIN

IN MECHANICAL VIBRATION

source is not easy to identify because the vibration isn't just one frequency but instead consists of a great number of driving forces superimposed on one another, forming a vibration spectrum. Then the task is to sort out these frequencies so that the most important constituents can be identified and traced to their driving forces.

These constituents can be identified easily by electronic instruments called spectrum analyzers. This class of instruments is gaining an important role in mechanical design because of its usefulness in such applications as controlling vibration in machine tools, improving the ride of automobiles, and providing smoother operation of construction and farm machinery.

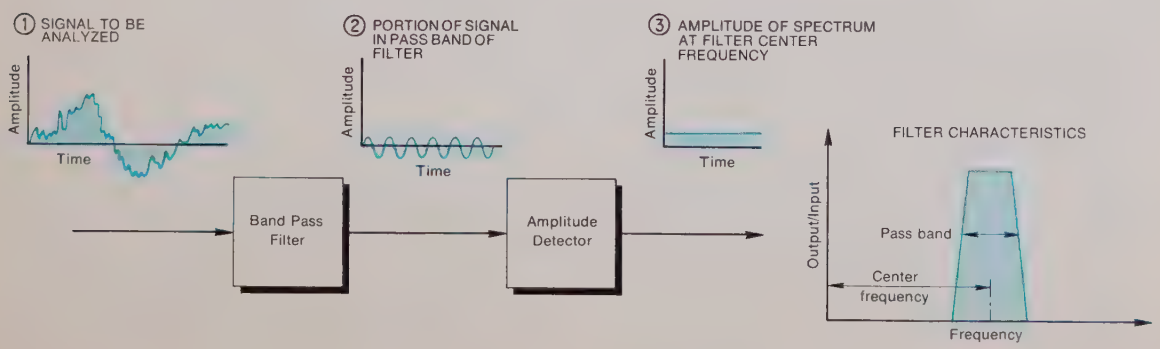
Not all spectrum analyzers are alike. Instead, they have varying capabilities in the precision with which they can identify frequency constituents. Since some of the more sophisticated models carry substantial price tags, and since the buyer "gets what he pays for," he should thoroughly understand what his money buys with the more expensive models. Or perhaps more important, he should know what he doesn't get with less expensive models.

Many types of vibration, not easily recognized in the time domain, exhibit distinctive signatures in the frequency domain. Merely recognizing these signatures often suggests methods for stopping the vibration.

Spectrum analysis can be performed by various types of equipment ranging from simple band-pass filters to sophisticated fast Fourier transform (FFT) processors. The signal being analyzed is a time-variant voltage (proportional to some physical variable such as motion or force). The spectrum display normally is an *X-Y* plot or oscilloscope trace.

Filtering Is the Key

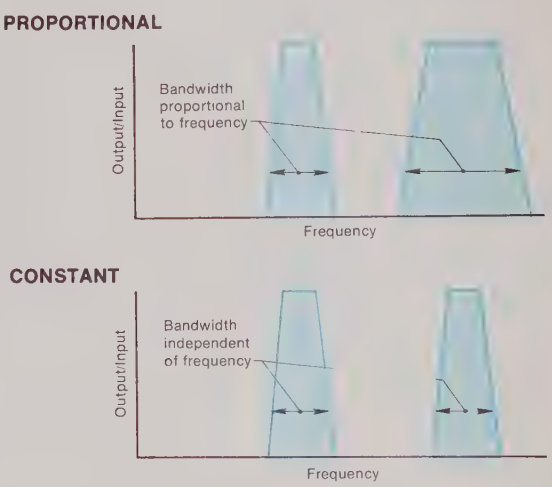
Regardless of the type of hardware employed to perform a spectrum analysis, the net effect is equivalent to passing the signal through a set of band-pass filters and detecting the amplitude of each filter output. The amplitude from each filter is a point in the spectrum, recorded as the spectrum amplitude at the center frequency of the filter.



Proportional vs Constant Bandwidth

Characteristics of band-pass filters determine the resolution of the spectrum analysis. Filters are classified broadly as exhibiting either proportional or constant bandwidth. As the name implies, the bandwidth of a proportional filter is proportional to its center frequency. (It "passes" a large bandwidth if it is a high-frequency filter or a much narrower bandwidth if it is a low-frequency filter.) Accordingly, these filters provide high resolution at low frequencies and low resolution at high frequencies. Common types of proportional filters include octave (bandwidth 71% of center frequency) and one-third octave (bandwidth 24% of center frequency).

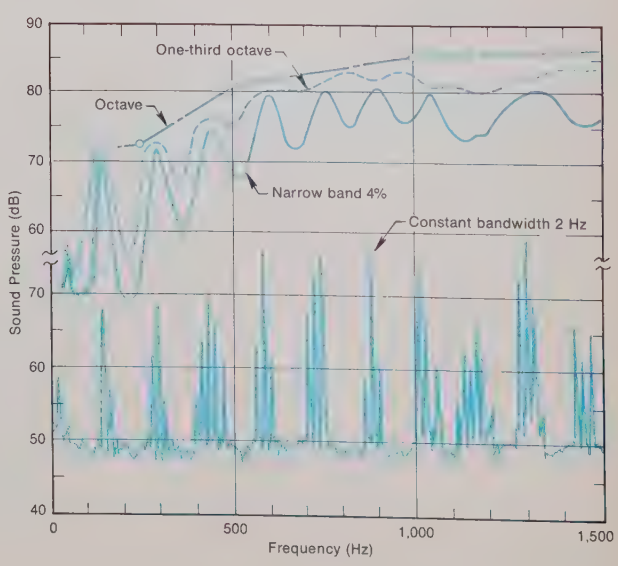
Bandwidths of constant-bandwidth filters are the same regardless of center frequency. Thus, resolution is the same for all frequencies. Constant-bandwidth measurements can be made by techniques including the use of sweeping filters, time-compression real-time analyzers (RTA), and fast Fourier transform (FFT) analyzers.



Four Views of the Same Signal

Here is an analysis of the noise emitted by two rollers in direct contact, one roller turning at 8,220 rpm (137 Hz) and the other at 17,400 rpm (290 Hz). With octave-band analysis, the noise appears to be primarily "white" with nearly equal energy above 250 Hz. With one-third octave analysis, some localized peak frequencies are detected at low frequencies, but behavior appears to be "white" at high frequencies. The 4% bandwidth filter begins to hint that there may be very definite bands of energy concentration, but resolution is poor at high frequencies. Finally, the constant-bandwidth analysis reveals that every significant "spike" in the noise spectrum can be accounted for by the frequencies of roll rotation, their harmonics, and sums and differences of these harmonics.

Thus, proportional bandwidth measurements can grossly categorize noise problems but normally cannot identify the noise producing



mechanism. Only the constant-bandwidth analysis reveals that the noise comes from the roll finish and mating qualities and does not involve local resonance or other characteristics of the driving hardware. (See *Origins of Noise,* MACHINE DESIGN, May 1, 1969.)

Ways to Plot a Spectrum

As just demonstrated, constant-bandwidth analysis provides more information (or resolution) than proportional-bandwidth analysis. Constant-bandwidth measurements can be made either by a scanning filter that makes measurements by moving up and down the frequency spectrum, or by instruments that measure all frequencies simultaneously.

The scanning method uses a single filter that has a constant bandwidth but a variable center frequency. For a spectrum analysis, the filter is "tuned" across a range of frequencies while its output is fed to an *X-Y* plotter.

This tracking process is slow. The minimum time required to measure a spectrum is directly proportional to the range of frequencies analyzed and inversely proportional to the square of the filter bandwidth. For example, analyzing a signal over a 1,000 Hz range with a 2 Hz filter requires at least 250 sec (1,000 Hz ÷ 2^2 Hz/sec). The signal content must not change for this duration.

This limitation restricts the use of scanning techniques to signals having a spectral content that does not change appreciably over long periods. Pressure pulsations in a hydraulic system operating under constant speed and load could, for example, be analyzed by the scanning method.

Most signals, however, change fairly rapidly, so all frequencies must be measured simultaneously. Such measurements can be done with a time-compression real-time analyzer, a fast Fourier transform processor, or by a multiplicity of filters. Regardless of the method, the result is equivalent to using a bank of parallel filters.

Using parallel filters for constant-bandwidth analysis is impractical because several hundred filters would be required. (In contrast, with *proportional* band analysis only 31 filters are needed for a typical audio-band ⅓-octave analysis.) But the net effect of hundreds of parallel filters can be gained by either of two synthesizing techniques: time-compression or Fourier transformation. These techniques are radically different in implementation but equivalent in terms of results.

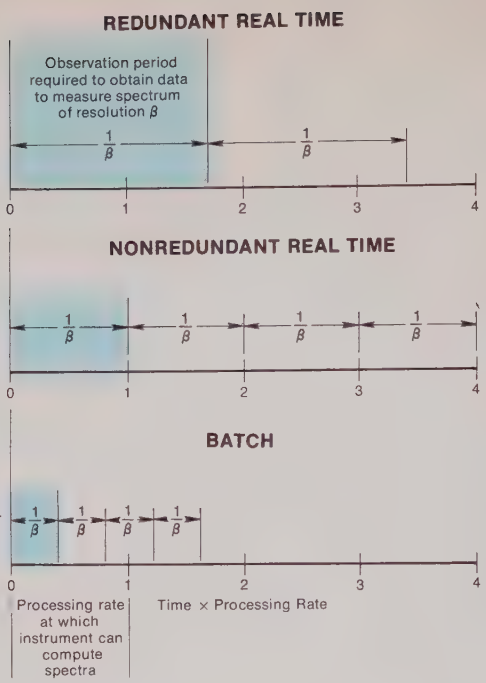
Typical spectrum analyzers of either type produce several entire spectra per second. This rapid computation and display of spectra by time compression or Fourier transformation has made on-line (or "real-time") frequency analysis a practical tool that can track dynamic variations as they actually occur.

Measuring in "Real Time"

The term "real time" as applied to a spectrum analyzer means that the instrument can present a continuous graphical display of a spectrum while the event being measured is actually taking place without missing any portion of the event. A real-time analyzer (RTA) measures spectra repetitively at a synchronous rate (spectra per sec) determined by the internal design of the instrument. To be in real time, this rate must equal or exceed the bandwidth (Hz) of the filters synthesized.

Real-time analyzers compute each spectrum displayed from a sample or "snapshot" of the measured signal. These analyzers always observe a snapshot of duration equal to the reciprocal of the bandwidth of the filters synthesized. This condition is necessary because the resolution reciprocal is the minimum time required for the output of each filter to be determined only by input. Whether the filter is real or simulated, any snapshot of shorter duration yields a filter output containing filter transient response as well as the desired steady-state response. Thus, when the computation takes place in a resolution reciprocal period (or less), the analysis is in real time.

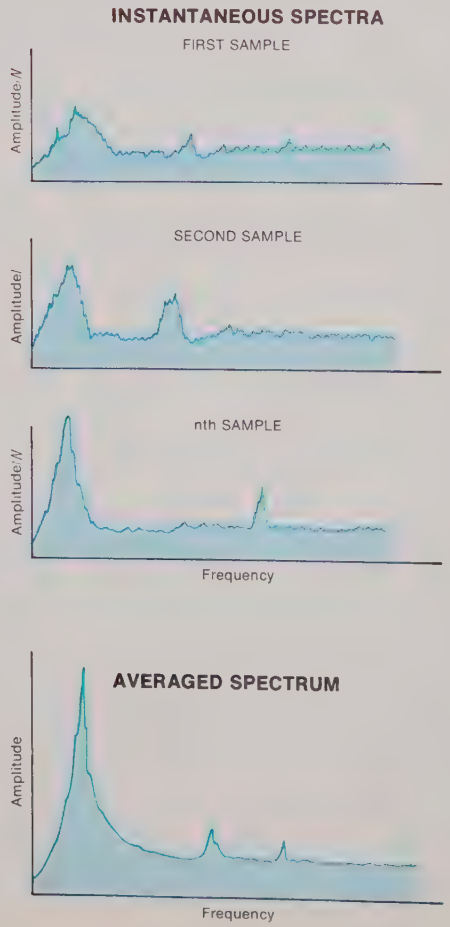
When the computation rate (spectra per second) is less than the resolution bandwidth, the meas-



urement is no longer in real time. Although spectra are still displayed at a rapid rate, portions of data are passing by without being analyzed. This situation is termed batch processing. When the computation rate exceeds the resolution bandwidth, successive spectra are not statistically independent because they are computed from overlapping information. This type of operation is called redundant analysis.

As the filter bandwidth decreases, the spectrum becomes more resolute, but the time required for a computation increases. For example, one second of data is required to analyze a signal to 1 Hz resolution, while 10 seconds is required to analyze to 0.1 Hz resolution. This relationship is governed by the physics of the measurement and is true regardless of the type of analysis equipment employed.

An Average Tells the Story



Real-time analyzers compute spectra as rapidly as filter theory permits. Each computed spectrum correctly describes the frequency content of its corresponding time-domain "snapshot." However, this spectrum is only an estimate of the frequency content of a continuous signal because frequency characteristics may fluctuate with time. If the spectrum measurement is to be exact, the snapshot obviously must cover a time period as long as the entire event.

With the measurement of a spectrum spanning a long time period, the answer (or its approximation) is not available until the end of that period. Furthermore, the measurement may contain far more resolution than anybody needs. For example, if an event lasted 15 minutes, a single spectrum (available only after the fact) would have a resolution of 0.111 mHz.

If the event had frequencies from DC to 2 kHz, the spectrum would have 1.8 million frequency points. This precision is unnecessary for most practical applications.

Therefore, most RTAs provide an alternative. Sample spectra are measured at a rapid rate (several per second) and averaged on a frequency point by frequency point basis. This technique, called ensemble averaging, is a means for obtaining reasonable resolution in both time and frequency domains simultaneously. The resultant has the same frequency resolution as each constituent

spectrum, and the average may be displayed as it is being computed.

When the averaging process has just begun and only a few "snapshots" have been processed, the displayed spectrum is an approximation of the long-term spectrum. As the averaging continues, the displayed spectrum converges on the final spectrum asymptotically.

In a practical sense, this rapid convergence means that a close approximation of an exact spectrum can be obtained quickly. For example, if the 15-minute × 2 kHz signal is measured with a 400-line analyzer, a spectral estimate with 5 Hz resolution is available after only 0.2 sec of data is sampled. Averaging 32 such spectra produces a spectrum within 1 dB of the long-term spectrum at every filter location (with 90% confidence). A real-time analyzer/averager produces this result in 6.4 sec.

Ensemble averaging assumes the signal to be statistically "stationary." A stationary signal exhibits the same ensemble-averaged spectrum regardless of when that spectrum is measured. The time period over which the spectrum must be averaged to obtain this stationary characteristic is determined by the signal and the degree of resolution desired in the measurement. It is this repeatability or stationary quality that gives machinery distinctive "signatures."

Ensemble averaging can be conducted over a fixed time period by averaging a preset number of spectra. Alternatively, a continuous moving time average (with constant statistics) can be produced by exponentially discarding old spectra while acquiring new data. This procedure permits the study of time-variant signals with high statistical confidence. Also, in some instruments, background characteristics may be excluded from a measurement by subtractively averaging the ambient conditions surrounding the event of interest.

What's Important in an RTA?

A real-time spectrum analyzer has three fundamental measures of merit. These characteristics define resolution in terms of amplitude, frequency, and time.

Dynamic range describes the ability to detect small signals among larger ones. Dynamic range is normally expressed (in dB) as the ratio of a full scale signal to the minimum signal level that the instrument detects without introducing errors. This specification reflects the characteristics of the entire instrument including its analog input circuitry, anti-aliasing filters, analog to digital converter, and spectrum processing circuits. Another important quality, *amplitude linearity*, defines the analyzer's ability to provide precise amplitude information within the dynamic range. Amplitude linearity is expressed as the worst case deviation (in percent of full scale) from an exact linear fit through the dynamic range.

Frequency resolution is a measure of the ability to distinguish between closely spaced frequencies. It is expressed as the number of filters synthesized across the frequency band being measured. This specification is closely tied to *frequency linearity*, a measure of the precision of center frequency placement for each synthesized filter. Frequency linearity is expressed (in percent) as the ratio of worst case filter placement error to the maximum frequency being studied.

Real time bandwidth defines processing speed. It is the maximum frequency range the instrument can analyze while processing in real time (rather than batch). The real time bandwidth (Hz) is numerically equal to the number of frequency points per second calculated and displayed by the instrument. In other words, the real time bandwidth is the product of the number of filters synthesized times the number of spectra processed per second.

Other features that can be useful include:

True power averaging (rather than voltage averaging) providing a true *rms* spectrum (rather than mean absolute value). Power averaging provides consistent statistics between narrow and broad-band signals.

Transient capture facilities to deal with short duration signals.

Automatically selected low-pass anti-aliasing filters to reject frequency components above the analysis range. These filters preclude misunderstanding the frequency content of the signal because of sampling errors that can be introduced by an analog to digital converter. MD

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New Product
Easier to understand noise or vibration.
444 MINI-UBIQUITOUS
FFT Computing Spectrum Analyzer
Built-in microprocessor in the 444 helps you by computing . . .
• calibration in linear engineering units, volts, V², dBV or dBR
• ratio and difference comparisons of spectra stored in dual memories
• 1/3 or 1/1 octaves in two additional memories (4 total)*
• A-weighted sound spectrum
• total signal RMS energy
• readings in CPM (RPM)
• harmonically related frequencies
• do-it-yourself logic troubleshooting*
Its basic performance . . .
• 400-line resolution, increased by as much as 2000:1 with built-in expander*
• ranges from 0-1 Hz to 0-100,000 Hz
• all-digital stability and accuracy
• report-ready digital plots fully labeled (thru RS232 interface*)
• ease-of-use
*optional
For a demonstration on your data at your facility, call Dick Rothschild at 201-767-7100.
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Circle #170 for
#171.)

NICOLET SCIENTIFIC CORPORATION

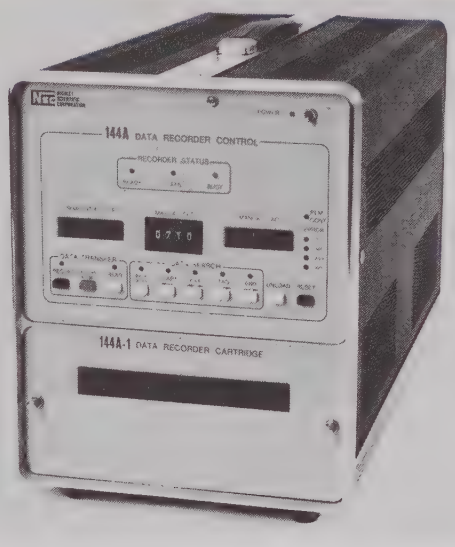
DATA RECORDER

MODEL 144A

A fast, efficient means of digitally storing thousands of noise or vibration spectra in factories, at refineries, aboard ships, at nuclear reactors, and at test tracks

PROBLEMS SOLVED:

- ★ **Changes in machine vibration are detected on-the-spot by comparing today's signature with any one of thousands taken months or years ago.**
- ★ **Short duration tests are completely analyzed on-line by rapid storage of successive spectra and/or transients (as time functions) for later viewing, measuring, and/or plotting in the lab.**
- ★ **Under difficult field conditions, simple push-button recording eliminates awkward X-Y plots or polaroid photos with their fragile paper records.**
- ★ **Completely repeatable records are stored conveniently in large quantity with full dynamic range and control setting information preserved permanently, with easy automatic retrievals by identification numbers.**



The 144A Data Recorder, in combination with a 444 or 440 MINI-UBIQUITOUS® FFT real-time Spectrum Analyzer performs the following functions:

RECORDS thousands of 400-line frequency spectra or 1024-sample time functions on-site, quickly, easily, and accurately, together with all the Analyzer annotation indicating control settings.

RECALLS any record automatically by searching for either a sequential 4-digit file number or a 4-digit operator-inserted tag number.

READS stored data into the Analyzer's memories. The control settings are displayed for understanding of how the data was processed. (Range, amplitude, amount and type of averaging, etc.)

The Data Recorder is lightweight and small, allowing it to be easily carried with the analyzer to the source of the signal for on-line analysis and recording.

IDENTIFICATION OF RECORDS

The operator can insert a 4-digit "tag" number at the time of recording which indicates some other condition of the test, such as RPM, Date, Time, or Transducer number. A 4-digit sequential "file" number is also automatically recorded with the data, simplifying retrieval.

Since recording time is a fraction of a second, many functions taken from a short duration test can be stored quickly and accurately. Recording merely requires a momentary push of a button. Data recording is fully compatible with the (proposed) ANSI Spec. BSR X3.56.

STORAGE:

Input time data, captured in the Analyzer's input memory, a single 400-line spectrum, or the average of many random spectra can be recorded with automatic identification of what the stored data represents. The test conditions, as reflected in the Analyzer's control settings, are completely preserved for later recall. These include:

- ☆ Input amplitude range
- ☆ Frequency range
- ☆ Display expansion
- ☆ Whether data is time, spectrum or averaged spectrum, and if averaged, how many spectra in the average
- ☆ Whether it is "weighted" or not
- ☆ If the vertical and horizontal display scales are logarithmic or linear

STORAGE CAPACITY

The recording medium is a 4-track 3M digital tape cartridge. Up to 1500 complete frequency functions or time functions* can be stored on one tape. A few cartridges can store thousands of records, enough to provide a complete library of machine signatures from hundreds of pickups obtained over months or years. All this data can easily be carried to the field for fast recall and comparison with current signatures to highlight changes in machine operation.

*If only time functions are recorded, the maximum number is 1000.

Note: All specs subject to change without notice

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In order to protect previous recordings, new records are automatically added only after the last recording. Without "initializing" the entire tape for reuse, the operator cannot inadvertently erase any data previously stored.

RECALL

When the desired record has been located by "file" or "tag" number, the push of a button restores it to the Analyzer's memory. In the case of time functions such as transients it is placed in the input memory; in the case of frequency data it is placed in the averager memory. It then can be measured, photographed or plotted on a standard X-Y plotter.

MANUAL SEARCH

If the operator desires to observe data previous to the current record, he can *backspace* one record at a time. If he wishes to manually scan through past data, he can *advance* one record at a time. In each case, the sequential "file" number, read on front panel LED's, indicates the record being read.

AUTOMATIC SEARCH

The recording can be searched for either a "file" or "tag" number. In the case of a "file" number, the Recorder will sense the number as set on the thumbwheel switches and decide whether to search forward or backward. In the case of the "tag" number, it only searches forward. Using a "tag" number, it is easy to locate all records, for example, from the same transducer which have been identified with the same "tag".

SPECIFICATIONS

Medium: 3M Data Cartridge, DC300A with 300' computer grade ¼" tape.

Capacity: In excess of fifteen hundred 400-line spectra or one thousand 1024 sample time functions; spectra and time functions may be intermixed.

Tape Speed: 30 inches per second read/write, 90 inches per second rewind.

Recording Format: 4 track, phase-encoded data at 1600 bits per inch; data recording in full compliance with the applicable ANSI specification.

Operating Times:

a. 250 ms to read, transfer, and display each spectrum; 450 ms for each time function

b. 350 ms to record each spectrum; 550 ms for each time function

c. Search speed is 240 spectra/minute

d. 40 sec to rewind tape from end to end

Data Identification: 4-digit sequential file number and 4-digit operator-set tag number both automatically appended to each record.

Data Display: Via Analyzer's CRT with full annotation. File and tag numbers are displayed on 144's front panel LED's.

Weight: 13 kg (28 pounds)

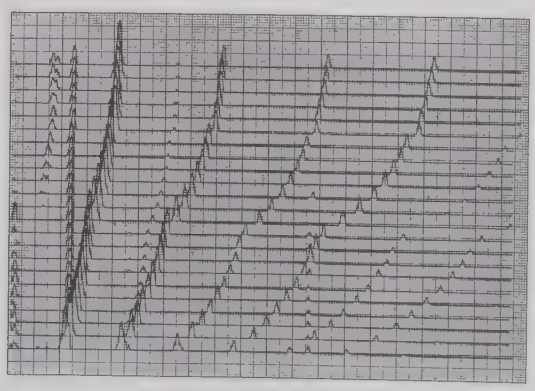
Power: 115V AC ±10% or 230V AC ±10%, 85 watts nominal

Size: 32.6 cm (12.9 inches) high x 25.4 cm (10.0 inches) wide x 51.9 cm (20.4 inches) long

Storage Temperature: (140A) -55° C to +85° C (DC300A Cartridge -40° C to +45° C)

Operating Temperature: Limited by tape to +5° C to 45° C

TYPICAL STACKED PLOT COMPARING MACHINE SIGNATURES. *Spectra, previously stored in the 144 Data Recorder, provide a visual comparison of past signatures with current ones to highlight anomalies which may indicate impending machine failures. Spectra were not normalized to rotational speed in order to reveal speed changes, such as those of "Feb 3" and "Mar 3". Approximately 10 rotational orders are shown.*



TIME HISTORY OF SPECTRA OF A MOTOR STARTUP. *The 144 Data Recorder stored many spectra during motor runup, which was too rapid to allow on-line X-Y plotting. Later recall of the spectra from the recorder provided the time history plot of the spectra. (Note that harmonics associated with the motor speed increased in frequency, whereas the 120-Hz power line frequency remained constant.)*

99J TRANSIT CASE . . .

a reusable shipping container for: 440A Series MINI-UBIQUITOUS® FFT Real-time Spectrum Analyzer + Model 51 Transducer Kit + Model 61 Recording Adapter Camera + spare filter + misc. cables + instruction manuals + power cord.

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INTERFACING TO THE MINI-UBIQUITOUS® 444A SPECTRUM ANALYZER:

Mini-Answers to Some Mini-Questions

INTRODUCTION:

For a quick overview of interfacing to the Model 444A Spectrum Analyzer, this technical note should be sufficient. (A more detailed description of interfacing is presented in Interfacing To The Model 444A Spectrum Analyzer: A Not-So-Mini Discussion On A Not-So-Mini Topic. For complete interfacing information, refer to Section V of the Operating Manual of the Spectrum Analyzer.)

WHY DOES INTERFACING SEEM SO COMPLEX?

The subject of interfacing to the 444A is complex because there are so many different ways of interfacing. Some interfaces simplify communication with specific devices. Other interfaces are kept sufficiently flexible to act as universal, general purpose (GP) interfaces.

The analyzer has the possibility of interfacing in at least twelve different modes; three analog and nine digital. This versatile capability, however, does cause some difficulty in understanding its features and characteristics.

WHAT INTERFACES CAN BE PROVIDED?

Analog:
1. External Monitor Scope, like the HP 1300 series
2. External Storage Scope, Tektronix 613
3. X-Y Analog Plotter

Three general purpose, bi-directional digital interfaces for use with intelligent devices:
1. Bit-Serial (RS232C), ASCII format (Option -07)
2. Byte-Serial ASCII format (Option -07(HP) for HP 9800 series calculators)
3. Parallel (20-bit-wide word) Coded Binary format (external Model 41 Computer Interface Unit converts from 20-bits to 16-bits for 16-bit mini-computers)

Five dedicated digital interfaces that communicate with specific devices and are initiated by the front panel STORE-CRT button:
1. Model 144A Tape Recorder (uses parallel bus)
2. Tektronix Digital Plotter, Model 4662 (uses RS232 Option -07)
3. "One-Way" RS232 (uses RS232 Option -07)
4. Tape Reader (uses byte-serial bus Option -07HP)
5. Tape Punch (uses byte-serial bus Option -07HP)

And finally, there are parallel interfaces, specifically designed for use with external A/D converters, where counting assistance can be provided to indicate when a data block has been loaded.

Thus, it is easy to understand the decisions one might have to make interfacing to the Model 444A analyzer. Some additional questions and answers will shed more light.

WHAT ABOUT IEEE488 or HPIB?

These are 8-bit parallel interfaces with listener/speaker bus protocol and will require a separate adapter (which NSC is considering as an option).

Nicolet Scientific Corporation
May 1977

245 Livingston Street
Northvale, NJ 07647

WHAT IS MEANT BY "GENERAL PURPOSE" INTERFACES?

The general purpose interfaces permit bi-directional communication with intelligent external devices. These interfaces permit:

1. Control of analyzer settings
2. Sense of analyzer settings and status
3. Load of time or spectrum data to the analyzer
4. Un-load of time or spectrum data from the analyzer

No front panel controls are required to initiate this type of communication. Instead, all the action is initiated (through rear panel connections) by the external device. That device, however, must be capable of transmitting and receiving data in our format.

WHAT IS THE BIT-SERIAL RS232 GP INTERFACE PROTOCOL?

It is basically simple. It uses a twenty-five pin rear panel connector, wired per RS232 specifications. The signal amplitude characteristics meet the same specification. The signals are not TTL. There is one wire for the input signal, one wire for the output, a ground wire and two lines called "Request to Send" and "Clear to Send".

The analyzer is considered the Data Communications Equipment and the external device, the Data Terminal Equipment. This means the external device is the "smart guy" and the analyzer is the "dummy". When the "smart guy" (external device) wants to talk to the analyzer, it says so ahead of time by sending a "Request to Send" signal. No data can be sent until the analyzer comes back with an o.k. ("Clear to Send" response). The external device then sends over eight bits in serial fashion (seven bits for the ASCII character, and one bit for parity). Having received a full ASCII character, the analyzer shuts off its "Clear to Send" in order to have time to digest the data. If more than one character is sent over, the external device can keep its "Request to Send" line active, but it must look at the "Clear to Send" before sending over the next character.

One might say the external device is "polite" in that it asks permission to talk, waits for an o.k., and then talks, one ASCII character at a time.

Is the analyzer equally polite? No. When the analyzer sends information to the external device, it assumes that the device is always ready to accept the data when sent, and no "handshake" takes place.

Therefore, the protocol is:

1. External device sends "Request to Send".
2. Analyzer sends o.k., "Clear to Send".
3. External device sends one character, and continuously watches the "Clear to Send" for an o.k. status.
4. If the command to the analyzer calls for data to be sent to the external device, then when the analyzer is ready to send, it does so.

Since the analyzer behaves in a fashion similar to a modem, we say that the analyzer interface emulates that of a modem. (It does not, however, interface to a modem.)

WHAT DATA CAN BE TRANSMITTED ON THE BIT-SERIAL BUS?

Several types of data can be transmitted: analyzer control information, time or spectrum data (both ways), sense data, and special instruction commands to the analyzer.

Special, single ASCII command words act as instructions to the analyzer to perform unique operations. Some of these single characters are:

R - A master re-set that clears and resets the analyzer including the Averaging and the Averager counter.

S - Send all sense information to the external device

T - Transmit either time or spectrum data to the external device, depending on which is displayed

L - Return control of front panel settings to local control

Etc.

Four special characters are sent to the external device by the analyzer. These are:

LF - Line feed
CR - Carriage return
ETX - End of transmission
CTRLG - Control G (Bell) to indicate error in data received by the analyzer

The CR and LF can be inhibited by an internal analyzer switch. Except for these special characters, all communications are via five ASCII character groups used to generate a twenty-bit analyzer word. The analyzer internal word consists of a sixteen-bit data field, and a four-bit identification tag indicating what the sixteen bits represent. Each ASCII character is used to transmit four bits of binary information (hexa-decimal number). The first four ASCII characters transmitted are re-constructed to form the sixteen-bit data field, and the fifth character represents the tag. If the CR and LF symbols are used in the outward transmission, they would occur after each five-character group to permit listing on CRT-type terminals, one analyzer word below the other.

If a control word is sent with the wrong tag code, the analyzer will not accept the data and will send back a CTRLG (bell) character.

WHAT ELSE CONCERNING THE GP BIT-SERIAL INTERFACE?

First, the parity bit is ignored by the analyzer and is set to a zero condition on all outward transmissions.

Second, the baud rate is selectable inside the analyzer to accomodate rates of 110, 150, 300, 600, 1200, 2400, 4800, and 9600.

Third, no special front panel controls are required for this interface. The analyzer is always receptive to communication via this port. (The RS232 connector can also be used to talk to the Tektronix 4662 Digital Plotter, under command of the front panel STORE-CRT button.) Even if this dedicated condition is set up, removing the Tektronix plotter plug from the analyzer and substituting the external device still allows a full RS232 bi-directional communication to take place.) Intelligent, full bi-directional interfaces will always exist and cannot be locked out.

HOW ABOUT THE GP BYTE-SERIAL INTERFACE?

This interface is used by HP9800 series calculators and is specified as Option -07HP.

Byte-serial interface uses two fifty-pin connectors, J101 and J102. The signals are TTL compatible.

In byte-serial communication, eight bits of information are sent in parallel to and from the analyzer, on two buses. Each eight-bit byte represents an ASCII character, just as in the bit-serial case. The meaning of the characters is the same.

IS THERE A SPECIAL PROTOCOL FOR BYTE-SERIAL?

Yes. The "handshake" is now more bi-directional. The external device places the ASCII character on the input bus, and also signals this even by lowering an XFLG4 line. This signal indicates that the data is available on the input bus. The data must remain on that bus until accepted by the analyzer. When the analyzer can service this request, it takes the data and tells the external device by lowering a "Data Taken" signal (XCTRL). The external device then removes the data and re-sets the XFLG4, and, in turn, the analyzer re-sets its XCTRL. A complete ASCII character has thus been transmitted.

In the reverse mode, data is not sent to the device until it is ready. The external device is ready when it sends a "Ready" code and lowers the XFLG4 line. The analyzer places the ASCII character on the output bus and lowers an XCTRL line. When the device has accepted the data, it restores the XFLG4 line and the analyzer does the same with the XCTRL. Each ASCII character sent follows this protocol.

HOW FAST DOES THE ANALYZER SEND OUT DATA ON THE GP BYTE-SERIAL BUS?

Not including the time it takes the analyzer to get to its location in the program to start transmission (typcially 100 milleseonds), the output rate is external-device dependent. Unlike the bit-serial interface, with data output transmission once started (occurring at a fixed baud rate) byte-serial interface rates depend on completing a "handshake" for each ASCII character transmitted. Therefore, if the external device is slow, the output rate is slow. The output rate for time or spectrum data can be as high as 50,000 characters per second, or 500,000 baud.

WHAT ARE THE CODES FOR GP BYTE-SERIAL TRANSMISSION?

The codes are similar to the bit-serial in that special characters still exist and data and control information is sent in the form of five ASCII characters, used to reconstruct the twenty-bit analyzer word. (Complete tables for the composition of this twenty-bit word are presented in the other memos.)

WHAT ABOUT PARALLEL INTERFACE?

In parallel interface, the entire twenty-bit word is sent to and from the analyzer, broadside. There are no single-character commands, nor is ASCII formatting used.

WHAT FORMAT IS USED?

Since communication is now direct with the internal bus, the words must be according to the twenty-bit format, mainly sixteen bits for the data field, and four bits for the tag information.

HOW DO WE INPUT DATA (PARALLEL GP INTERFACE)?

First, place the twenty-bit word on the input bus, J101; tell the analyzer by activating the XFLG4 flag. The analyzer then does one of two things: First, it looks at the tag and checks to see if it is a correct tag. Some tags are not usable on parallel interface. If a correct tag exists, the analyzer accepts the data and returns a four-bit o.k. ("Acknowledge") code on the output bus, together with a pulse called the DXREAD. If the information tag is not correct, the analyzer will not accept the data, and it

will send out a not-acknowledge ("Try Again") code, a $\overline{\text{DXREAD}}$ pulse.

ARE THERE ANY SPECIAL CHARACTERS TO UNLOAD SENSE OR TIME DATA?

No. All important data appears on the output bus during one complete processing cycle. Therefore, the external device can "grab" what data it wants, and no special characters are needed.

WHAT ABOUT THE OUTPUT?

Since parallel interfacing gets very close to the actual internal bus of the analyzer, the external device "sees", so to speak, the actual data flow going on inside. Some of the data is meaningless to the external device and some is useful. The analyzer will identify useful data by supplying a four-bit tag and also outputting a $\overline{\text{DXREAD}}$ pulse, only for these words. The external device now can pick whatever data it wants as the data goes by.

HOW MUCH TIME DOES THE EXTERNAL DEVICE HAVE TO LOOK AT THE DATA?

Essentially, two microseconds. The width of the $\overline{\text{DXREAD}}$ pulse is two microseconds. During this time, the twenty-bit output word is stable. The external device must look at the four-bit tag to determine what the data is. If it can "grab" the data, it must do so in the two-microsecond interval, and can use the trailing edge of the $\overline{\text{DXREAD}}$ as a clock strobe. Although the data is stable only for two microseconds, another word will not appear, typically, for twenty microseconds. If the external device is fast enough to operate in the two microsecond-window, the output can be sent to the external device without affecting the internal operation of the analyzer.

Hold it! What if the external device is not so fast? Then build the circuitry to look at the tag information only, in the two-microsecond interval, to see if that is the data wanted. Then say, "halt", to the analyzer (separate "halt" line) and the data will stay on the output line until the device has taken the word. Note, however, that now the analyzer is stopped and no processing takes place. When the external device has taken the data, it can release the "halt" condition.

WHEN SHOULD GENERAL PURPOSE INTERFACES BE USED?

GP interfaces are used whenever there are intelligent external devices that want to control, sense, or transfer data to and from the analyzer under the control of that device. These types of interfaces require no front panel control.

WHAT ABOUT SPECIFIC DEVICES?

There is a class of not-so-smart external devices. These devices are semi-smart (or semi-dumb): They generally don't think completely for themselves. Therefore, these devices need some help getting started.

What provides this help? A button on the front panel called STORE-CRT.

If the STORE-CRT MODE switch (rear panel) is set to AUX, the unit will be able to specify a series of digital transmissions unique for a specific device. Since the communication must be started with the STORE-CRT button, this mode is called Dedicated Digital Interface.

WHAT DEDICATED MODES ARE THERE?

1. The Model 144A Tape Recorder uses a parallel interface (connectors J101 and J102). However, the operator wants to record data onto the tape only when he sees something interesting on the display. First, internal to the analyzer, he sets a rotary switch to the Model 144A Digital Interface position. When the RECORD button is depressed, all the display information is transferred to the tape recorder. In addition, in this mode, the tape recorder can feed information back to the analyzer.

2. RS232 "One-Way Only". If the external device will accept ASCII bit-serial output characters from the analyzer anytime it appears on the output, set the internal switch to one of three possible RS232 communication positions.

a. Sense and Real/Imaginary Spectrum Data
b. Sense and Time or Spectrum Data
c. Sense and Real/Imaginary Spectrum Data, and Time or Spectrum Data

Now, if the STORE-CRT button is activated, the analyzer will do one of the following:

For "a", it will send the sense information of the analyzer, plus the real and imaginary components if the instantaneous spectrum.

For "b", it will send the sense information and the time or spectrum data, depending on what is on the display.

For "c", it will send sense, real, and imaginary components of the instantaneous spectrum and time or spectrum, depending upon the display.

Since bit-serial is a slow transmission, depending on the baud rate, the analyzer should be placed in "hold" for all three modes so that the time or spectrum data is taken from the same input block.

What devices can be used? A terminal or printer with RS232 communication. If the line feed and carriage return characters are used, a listing of the status and data can be produced.

3. Paper Tape Reader interface. Set the internal switch to the paper tape reader mode. Here the byte-serial port is used. Pressing the STORE-CRT button starts the reader via a start strobe, reads one character from the tape, and stops. The characters must be in ASCII format and correspond to the format used for general purpose bit- and byte-serial communication. Communication continues with the tape reader, one character at a time, until the analyzer senses an ETX character, signifying end of data transmission, or until there is no response from the reader within three seconds.

4. Interfacing to a paper tape punch, set the internal controls for paper tape punch operation. When the STORE-CRT button is depressed, all the sense, the real and imaginary spectrum components, and either time or spectrum data (depending on what is displayed) are sent in ASCII character format over the byte-serial port. The end of this transmission is signified by an ETX character.

WHAT ABOUT THE DIGITAL PLOTTER?

This interface does not use the internal switch. Set the STORE-CRT MODE switch (rear panel) to PLOT and the interface is for a Tektronix 4662, via the RS232 connector. As you know, the Model 4662 plotter needs vector information to generate the graphs presented on our oscilloscope. When the STORE-CRT (front panel) button is pressed, the analyzer

generates special vector information. In order not to transfer data too fast, the internal baud rate on the analyzer should be set to 600. In addition, on the rear of the plotter, the ABCD switches should be set to "7222".

ANYTHING ELSE?

One more thing. The special parallel interface for A/D converters allows the loading of data directly into the input buffer using special timing control pulses. The analyzer takes care of counting the data. (Consult the factory.)

IS THIS WHAT MY SPECTRUM REALLY LOOKS LIKE? AN ILLUSTRATED GUIDE TO BETTER SPECTRUM ANALYSIS

by

Henry J. Bickel
Nicolet Scientific Corporation
Northvale, New Jersey

This paper is reprinted from "Proceedings of the Technical Program, Noisexpo, National Noise and Vibration Control Conference, New York, N.Y. March 29-31, 1976".

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Spectrum Analyzers Have Improved Greatly

A spectrum analyzer is an instrument which decomposes a signal into its frequency components. When high frequency resolution is desired, constant bandwidth analysis is usually appropriate. Fast Fourier transform (FFT) analyzers and so-called hybrid real-time analyzers (RTA) may be employed to decompose the signal into its constituent frequencies. When real-time spectrum analyzers first became available ten years ago, there was justifiable concern about what the spectrum analyzer did to the signal. Early instruments introduced spurious responses and had limited accuracy. Today, however, FFT analyzers have sufficient dynamic range, linearity, and frequency accuracy to eliminate the spectrum analyzer as a significant source of measurement errors. In fact, a good FFT analyzer will bring into view the effects of distortion introduced by signal sources, amplifiers, and recorders ahead of the spectrum analyzer. Such distortion may corrupt the spectrum of the signal which is of interest. I hope that the illustrations presented in this paper will assist in tracking down problems and improve the interpretation of spectrum analyzer outputs.

Why Spectrum Analysis?

Viewing the frequency content (spectrum) of a signal is often more informative than looking at the time history with an oscilloscope or a chart recorder. Many noise and vibration signals exhibit clearly identifiable spectrum "signatures" that cannot be easily recognized in the time domain. Recognizing the signature is frequently an essential and important first step to understanding and solving a problem. If the spectrum signature of a signal has been corrupted by some form of distortion we would like to know about it lest we attribute significance to completely spurious frequency components.

Portable FFT Analyzer Provides Illustrations

Figure 1 shows the instrument employed to obtain the illustrations used in this paper. The Model 440A is an FFT analyzer which computes a 1024-point transform. The unit provides 11 analysis ranges from 0-10 Hz to 0-20 kHz. On each analysis range the nominal frequency resolution is 1/400th of the highest frequency displayed. For example, when analyzing 0-1,000 Hz, the frequency resolution is 1/400th of 1,000 Hz or 2.5 Hz. For most purposes, we can think of the spectrum analyzer as providing performance equivalent to 400 equal-bandwidth contiguous bandpass filters.

The analyzer computes and displays the instantaneous spectrum of a time function and the power spectrum using various averaging modes. Transient signals can be captured and their time waveform can be viewed before spectrum analysis. For convenience and accuracy of display, the instrument generates an electronic graticule on its built-in display oscilloscope. Salient operating characteristics are annotated on the display screen, and a movable cursor allows accurate frequency and amplitude measurements to be made. For detailed specifications, see Reference 1. All oscilloscope photos were taken with a Polaroid CR-9 Land camera using Type 107 film.

Distortion Ahead of the Spectrum Analyzer

The data illustrated in the following figures are typical of results obtained using any high quality FFT analyzer. Most of the oscillograms shown employ a linear frequency axis (horizontal axis) with ten divisions. The letters DB along the vertical axis indicate that a logarithmic amplitude display of 60 dB range is used (10 dB per division). Further details of the display annotation are shown in Figure 2. For the purpose of the discussion which follows we need not study the annotation scheme in detail, however.

Sinusoidal signals are helpful for testing amplifiers and recorders which might precede a spectrum analyzer. However, in doing so we quickly find out that not all sine waves are equally good. Figure 3 shows the spectrum of a "clean" sine wave. The amplitude of the sine wave is approximately 10 dB below the full scale output of the spectrum analyzer. No second harmonic distortion can be seen. Some third harmonic distortion is visible between the seventh and eighth horizontal graticule marks.

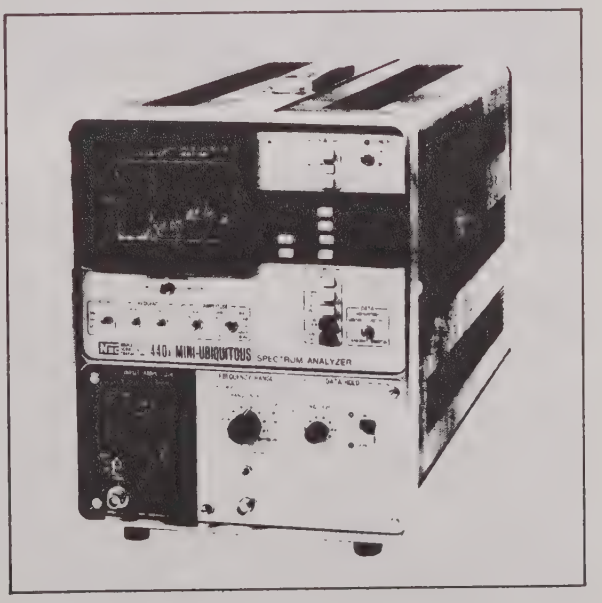

Figure 1. Mini-Ubiquitous® FFT Analyzer Model 440A.

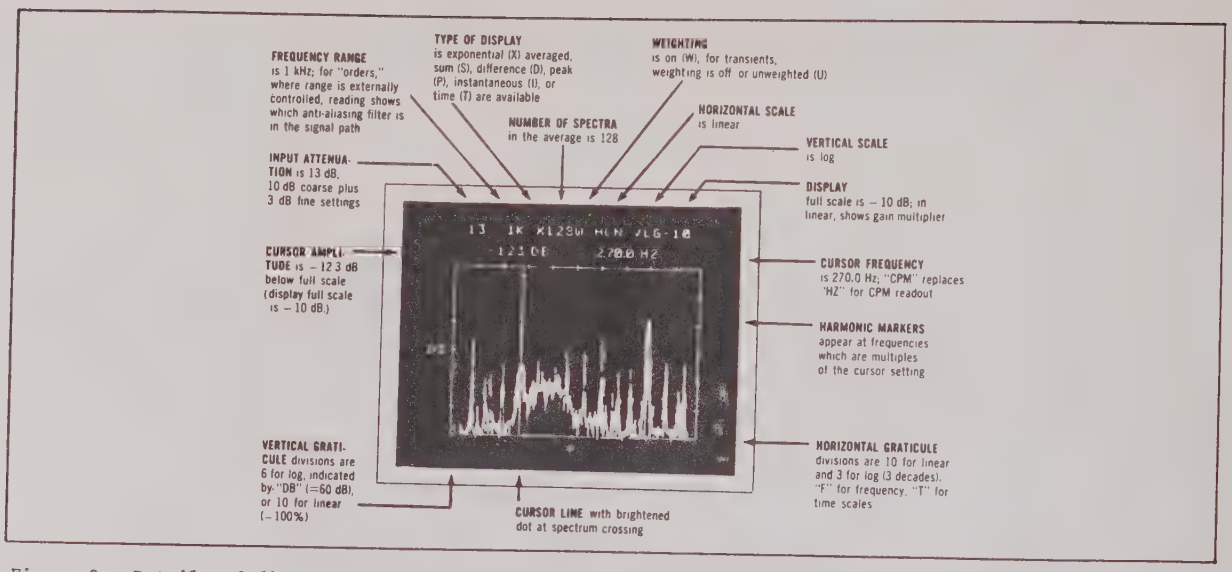
FREQUENCY RANGE is 1 kHz; for "orders," where range is externally controlled, reading shows which anti-aliasing filter is in the signal path
TYPE OF DISPLAY is exponential (X) averaged, sum (S), difference (D), peak (P), instantaneous (I), or time (T) are available
WEIGHTING is on (W), for transients, weighting is off or unweighted (U)
NUMBER OF SPECTRA in the average is 128
HORIZONTAL SCALE is linear
VERTICAL SCALE is log
DISPLAY full scale is – 10 dB; in linear, shows gain multiplier
INPUT ATTENUATION is 13 dB, 10 dB coarse plus 3 dB fine settings
CURSOR AMPLITUDE is – 12.3 dB below full scale (display full scale is – 10 dB.)
CURSOR FREQUENCY is 270.0 Hz; "CPM" replaces "HZ" for CPM readout
HARMONIC MARKERS appear at frequencies which are multiples of the cursor setting
VERTICAL GRATICULE divisions are 6 for log, indicated by "DB" (=60 dB), or 10 for linear (– 100%)
HORIZONTAL GRATICULE divisions are 10 for linear and 3 for log (3 decades). "F" for frequency, "T" for time scales
CURSOR LINE with brightened dot at spectrum crossing

Figure 2. Details of display annotation.

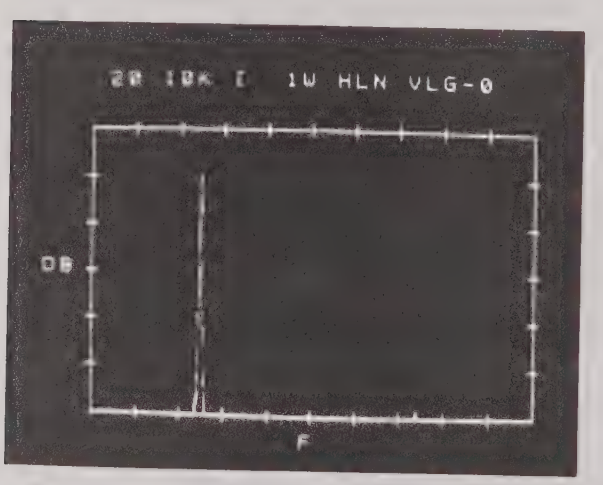

Figure 3. Spectrum of a "clean" sine wave.

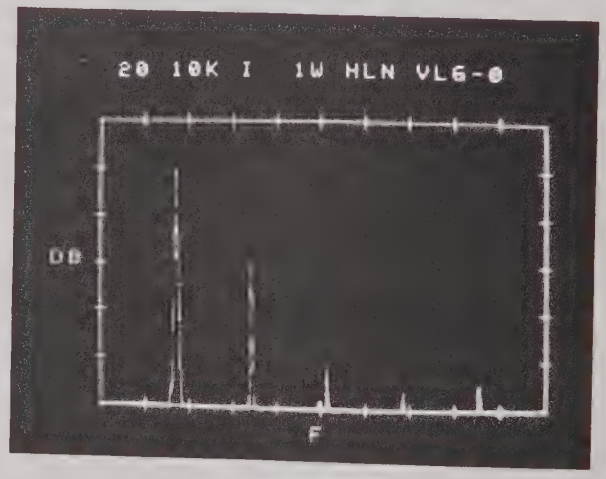

Figure 4. Spectrum of sine wave rich in harmonic distortion.

This distortion is approximately 50 dB below the fundamental amplitude of the sine wave. Inexpensive waveform generators which produce sine waves, square waves, triangular waves, etc. usually produce sine waves which are fairly rich in harmonics. A typical spectrum of such a sine wave is shown in Figure 4. The second harmonic is only 20 dB below the fundamental and additional harmonics are clearly visible in the spectrum. The sine wave whose spectrum appears in Figure 4 is not well suited for checking out a spectrum analysis system and its associated instrumentation.

Spectrum Distortion in Tape Recorders

Noise and vibration signals are frequently recorded on tape for subsequent spectrum analysis. It is well worth running a few simple tests on the tape recorder in order to determine the extent to which played back data will differ from the original signal. Figure 5 shows the spectrum of a sine wave applied to a brand new $150 cassette recorder. Figure 6 shows the spectrum of the reproduced sine wave. As expected, the spectrum of the reproduced sine wave is smeared (widened) considerably starting approximately 30 dB below the fundamental amplitude. This smearing or widening of the spectrum is due to perturbations in the tape movement as a result of tape stiction, flutter, and wow. Also, a second harmonic which was not present in the input signal to the tape recorder has become visible. Even expensive instrumentation recorders can easily go out of adjustment and it is really essential to run the simple test illustrated in Figures 5 and 6 in order to define the measurement limits imposed by the tape recorder.

A spectrum analyzer in combination with a good broadband noise generator is a very handy tool for checking the frequency response of amplifiers, tape recorders, etc. Figure 7 shows a "flat" (also

called "white") power spectrum applied to a tape recorder. The power spectrum at the tape recorder output is shown in Figure 8. The shape of the spectrum curve reflects the frequency response of the entire tape recording system. The vertical line passing through the spectrum in Figure 8 is a cursor whose position is controlled from the analyzer front panel to make accurate amplitude and frequency measurements. The -3 dB bandwidth of the cassette recorder was found to be 6,350 Hz. Less than half a minute was required to check the frequency response of the recorder.

Intermodulation Distortion

The type of nonlinearities which cause harmonic distortion in amplifiers and tape recording systems also give rise to intermodulation distortion. To illustrate the effect, two equal amplitude sine waves at 3,000 Hz and 3,350 Hz were applied to an amplifier (see Figure 9). The amplifier was intentionally overdriven and Figure 10 shows the amplifier's output spectrum. In addition to harmonics of the input frequencies, the output spectrum contains sum and difference frequencies. The following are the dominant frequencies (Hz) present in Figure 10:

350, 700
2,300, 2,650, 3,000, 3,350, 3,700, 4,050
5,650, 6,000, 6,350, 6,700, 7,050
8,650, 9,000, 9,350, 9,700

Rotating devices such as motors, gear boxes and transmissions, fans, etc., produce complex spectra containing many discrete "lines." If such a complex signal passes through a bad amplifier, amplitude limiter, or other nonlinear device, a very large number of distortion frequencies will be generated thereby rendering the information contained in the spectrum nearly useless.

Caution at the Input to the Spectrum Analyzer

Certain cautions must be observed when using any type of spectrum analyzer which converts analog signals to digital numbers prior to spectrum analysis. In all such analyzers, serious signal distortion occurs when the dynamic range of the input ana-

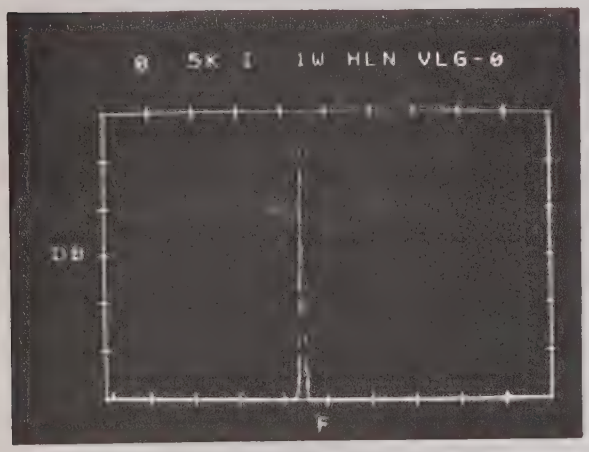

Figure 5. Sinusoidal input to tape recorder.

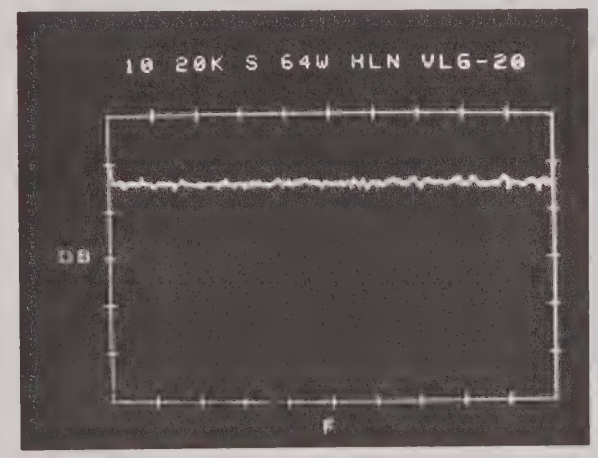

Figure 7. Flat power spectrum applied to tape recorder.

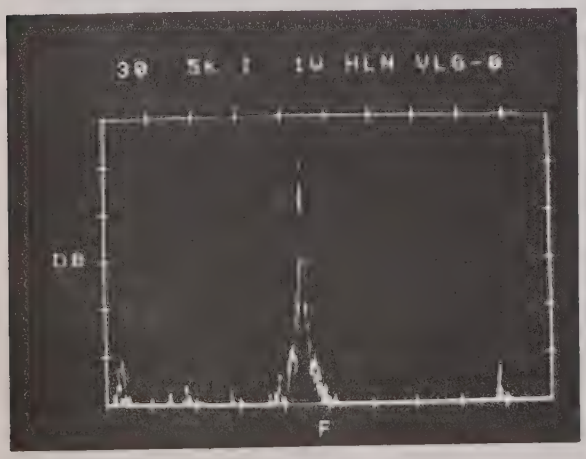

Figure 6. Sine wave reproduced from tape.

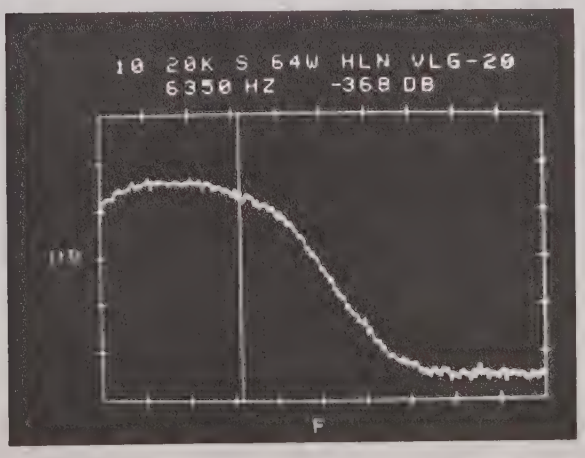

Figure 8. Power spectrum at tape recorder output.

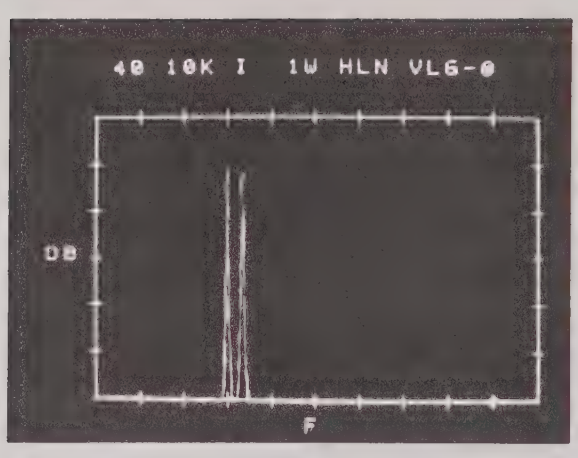

Figure 9. Input spectrum to amplifier (3000 Hz and 3350 Hz sine waves).

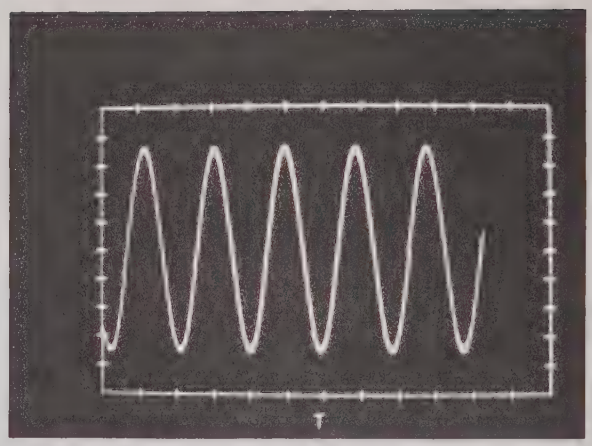

Figure 11. Analog signal within dynamic range of A/D converter.

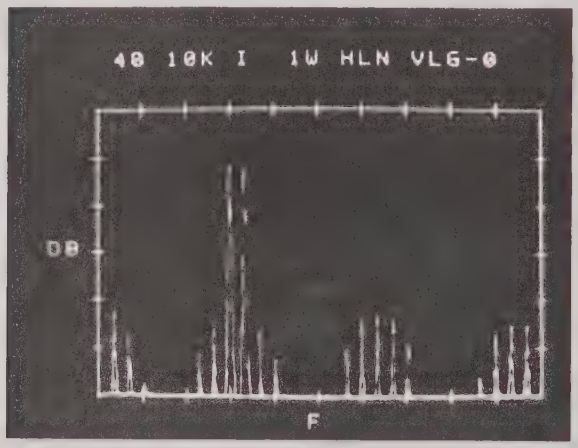

Figure 10. Distorted spectrum at amplifier output.

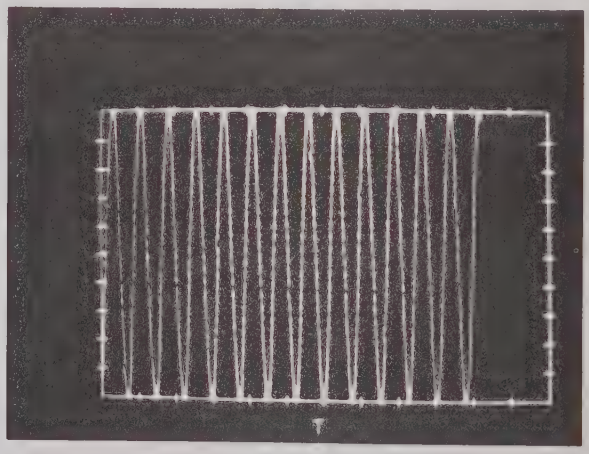

Figure 12. A/D converter dynamic range has been exceeded.

log-to-digital converter is exceeded. The distortion is particularly noticeable when analyzing periodic signals. Most digital spectrum analyzers use a type of analog-to-digital converter which acts as a hard limiter when the signal amplitude is in excess of the dynamic range of the converter. In the Mini-Ubiquitous® Analyzer Model 440A it is possible to convert the digitized time signal back to analog form in order to check for possible overload in the system. Figure 11 shows a sinusoidal signal within the dynamic range of the spectrum analyzer's A/D converter. In the figure, the upper and lower boundaries of the graticule correspond to the conversion limits of the analog-to-digital converter. Figure 12 shows a sine wave whose amplitude is a few percent greater than the digital conversion range. The distorted spectrum of the sine wave shown in Figure 12 appears in Figure 13. Note that odd harmonics are particularly large.

When signals are noiselike in nature, occasional overload (less than 1% of the time) of the A/D converter will usually not lead to noticeable distortion. However, persistent over-driving of the

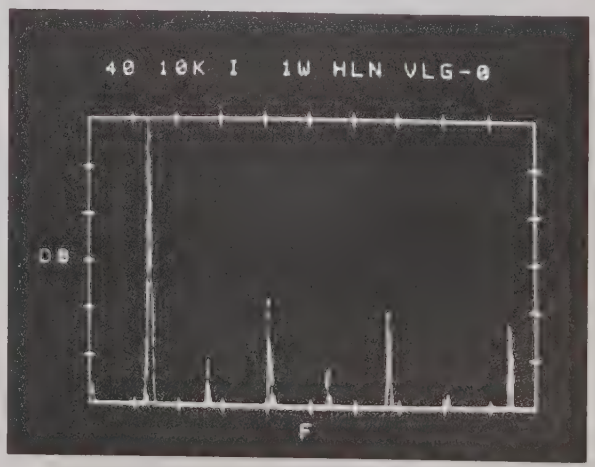

Figure 13. Spectrum distorted by A/D converter overload.

digitizing circuitry will cause problems. Figure 14 shows the power spectrum of noise having passed through a bandpass filter with a center frequency of 500 Hz and a bandwidth of approximately 30 Hz. Overloading the input to the spectrum analyzer leads to the distorted spectrum shown in Figure 15. The spurious noise peak is at 3 times the frequency of the "fundamental peak" because of almost symmetrical clipping resulting from A/D converter overload.

If at all possible, use an a-c coupled input to the spectrum analyzer. In most practical situations, the d-c level of a signal has little significance and letting a d-c level pass to the A/D converter will usually waste some of the dynamic range available in the instrument.

Anti-Aliasing Filters are most Important

Any properly designed digital spectrum analyzer must contain bandlimiting low-pass filters preceding its analog-to-digital converter. Almost always the input signal to be analyzed includes frequency components beyond the analysis range which is being used. These components must be attenuated by means of a low-pass filter which is called the "anti-aliasing" filter. Without proper anti-aliasing filtering, any digital spectrum analyzer will produce spurious frequencies. All Ubiquitous® analyzers incorporate properly designed anti-aliasing filters whose cutoff frequency is changed automatically as the analysis range is selected. Only the unaliased, i.e., undistorted, portion of the spectrum is displayed.

Theoretically, 512 frequency points can be obtained from a 1,024-point transform. However, it is not practical to design a system in which the theoretically maximum number of frequency points can be obtained without distortion. Realizable anti-aliasing filters do not provide infinite attenuation beyond the edge of their passband and for that reason a guard band must be provided in order to avoid spurious responses. In the Mini-Ubiquitous® Analyzer, 400 frequency points are generated which are

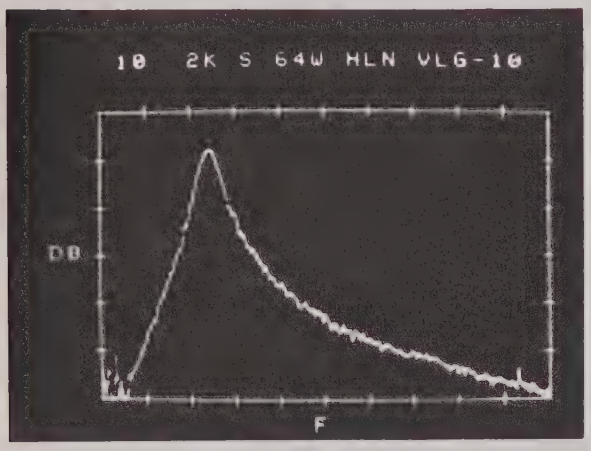

Figure 14. Power spectrum of bandlimited Gaussian noise.

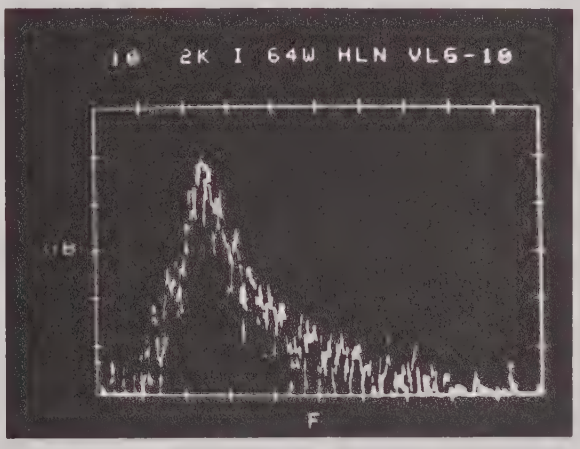

Figure 16. Instantaneous (unaveraged) spectrum of shaped noise plus sine wave.

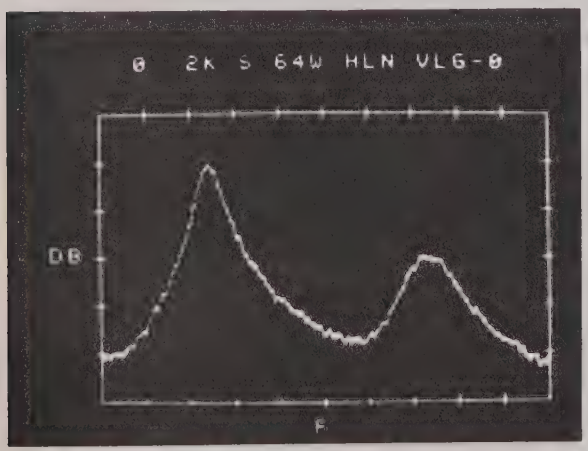

Figure 15. Noise spectrum distorted by A/D converter overload.

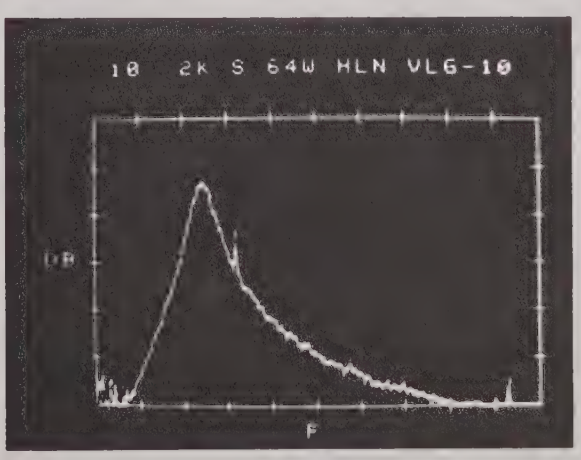

Figure 17. Power (mean) spectrum of shaped noise plus sine wave.

adequately protected against aliasing.

Vulnerability to aliasing is particularly great when we analyze a small portion of a broad spectrum. If we analyze 0-100 Hz of a spectrum whose frequency content extends beyond 100 Hz, the anti-aliasing filter is burdened with the task of rejecting most of the signal energy above 100 Hz. To check for spurious responses due to aliasing, apply a full-scale sine wave to the spectrum analyzer and move its frequency beyond the analysis range to which the instrument is set. As the frequency is increased you may find a spurious signal moving into the analysis band starting at the high-frequency edge of the range.

Averaging and Signal-to-Noise Enhancement

The spectrum of a random signal is in itself a random variable. Averaging is required to obtain good estimates of the power spectrum. Figure 16 shows the instantaneous (unaveraged) spectrum at the output of a bandpass filter which was excited by noise plus a sine wave. Because of its low amplitude, the spectrum line of the sine wave is not visible in Figure 16. After ensemble averaging 64 statistically independent squared spectra, the mean spectral characteristic (power spectrum) is clearly shown in Figure 17. The spectrum of the sine wave which had previously been buried in noise is now visible as a "line" just to the right of the noise spectrum peak.

It is important to know how many statistically independent spectra must be averaged in order to obtain a spectrum estimate of the desired accuracy. Curves showing the statistical stability of random spectra are contained in References 2 and 3 and are plotted as a function of "degrees of freedom." In most practical situations, degrees of freedom equals two times the number of statistically independent spectra which have been averaged. The data shown in Figure 17 represents an average of 64 statistically independent spectra and was computed in approximately 13 seconds (analysis range 2000 Hz, nominal bandwidth 5 Hz).

One of the unique features of the Mini-Ubiquitous® Analyzer is a digital averager which allows power subtraction of new spectra from previously averaged spectra in order to remove unwanted background signals or pickup. This mode of averaging is called "subtractive" averaging and its basic application is in determining the spectrum and total sound level associated with a source in an uncontrolled acoustic environment.

In making plant noise surveys it is usually impractical to shut down all machines in order to measure the noise of one particular machine. Using the "subtractive" averaging mode, it is merely necessary to shut down the one particular machine whose noise signature is desired in order to establish the "background" for subtraction purposes. Figure 18 shows the spectrum of the sine wave which appears in Figure 17 after subtracting the background "of shaped noise." Working with data which are not completely stable, the subtraction will generally not be as perfect as Figure 18 indicates.

Transient Analysis

FFT spectrum analyzers have the capability of performing theoretically correct analyses of transients. Such analyses require the use of a so-called uniform weighting function (also called rectangular or flat weighting function). Most digital spectrum analyzers employ cosine squared weighting (also called hanning weighting) when analyzing signals which are relatively continuous. A signal which persists for more than 2 or 3 times the reciprocal of the analyzer bandwidth may be considered continuous for purposes of choosing a weighting function.

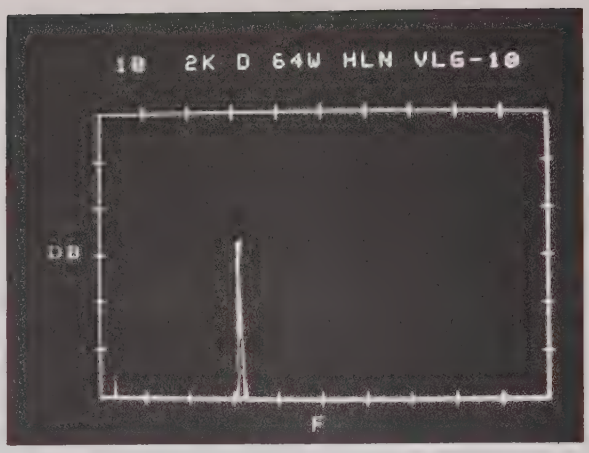

Figure 18. Spectrum of Figure 17 after subtraction of shaped noise "background."

Figure 19 shows the spectrum of a continuous sine wave using hanning weighting. The same sine wave analyzed with a "uniform" weighting function appears in Figure 20. Comparison of Figures 19 and 20 clearly illustrates how the hanning weighting function narrows the spectrum of the sine wave and greatly increases the ability of the spectrum analyzer to resolve frequency components which differ in amplitude but are relatively closely spaced in frequency. The subject of weighting is discussed in References 4 and 5.

Figure 21 shows the waveform of a transient captured in the memory of the FFT analyzer. Broadly speaking, the spectrum features of the transient have a width which is related to the duration of the transient. If half the transient's power occurs during P seconds, then the major spectrum peaks will have -3 dB widths roughly in the range of 1/P Hz (see Figure 22). The rule of thumb tells us that short duration signals have broad spectra and attainable analysis resolution may not be limited by the capabilities of the instrumentation, but by the characteristics of the signal.

Characteristics of Spectrum Analyzers

The term "real time" is frequently attached to a spectrum analyzer. Often, real time implies little more than that spectrum analyses are produced on-line relatively fast. The strict meaning of real time, however, requires an instrument that provides a steady stream of spectra in response to a stream of input data without missing any of the input data. When a spectrum analyzer operates beyond its real-time analysis capability, spectra are still being displayed at a rapid rate, but portions of the input

data are passing by without being analyzed. This mode of operation is termed "batch processing."

Typical FFT spectrum analyzers have a real-time bandwidth in excess of 1 kHz and thereby calculate at least a few spectra per second. This rate of computation is usually adequate for defining events which continue relatively unchanged over periods of seconds. If the spectrum of a signal is highly dynamic and it is important to observe all changes in the spectrum, higher real-time bandwidth may be required. Single transients can usually be handled by the spectrum analyzer without difficulty. The equipment becomes expensive if it is necessary to generate new spectra every 5 or 10 msec.

Frequency resolution is a measure of the analyzer's ability to distinguish between closely spaced frequencies. The 3 dB bandwidth is the conventional measure of bandwidth used when describing bandpass filters. It is a good indicator of the spectrum analyzer's ability to resolve two equal amplitude sine waves. The sharpness of a filter synthesized in a digital analyzer depends on the weighting function used. Figures 19 and 20 clearly illustrate the loss in sharpness resulting from use of uniform weighting. Nevertheless, uniform weighting is the proper function to use when analyzing most transients. The noise bandwidth (sometimes called effective bandwidth) is used to convert power spectrum measurements to power spectral density.

Frequency linearity is a measure of the precision of center frequency placement for each synthesized filter. In FFT analyzers, the frequency linearity is virtually perfect. Inaccuracies may occur when data are displayed or plotted using analog techniques. Typical oscilloscope display linearities are 2-3 percent. X-Y plotting accuracies of 0.2 percent full scale are not difficult to realize using good laboratory equipment. Digital readout from FFT analyzers by means of a "cursor" eliminates possible errors due to analog equipment.

Amplitude linearity defines the analyzer's ability to provide precise amplitude information within its dynamic range. In FFT's it is not too

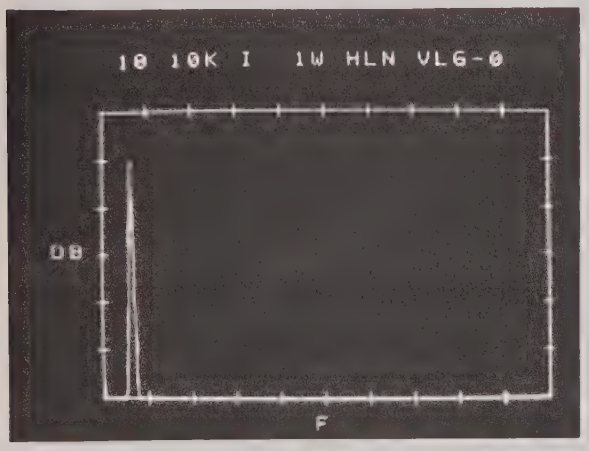

Figure 19. Sine wave spectrum using "hanning" weighting.

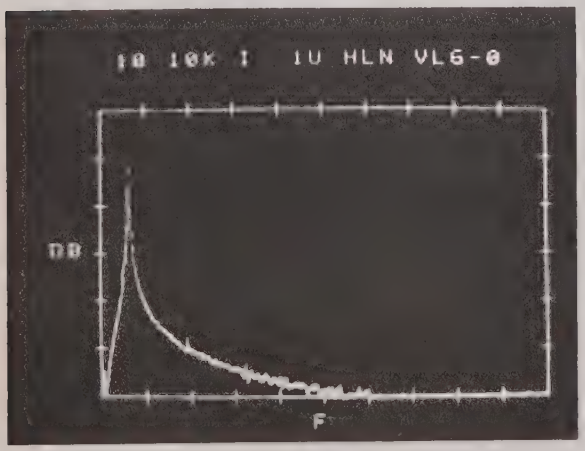

Figure 20. Sine wave spectrum using "uniform" weighting.

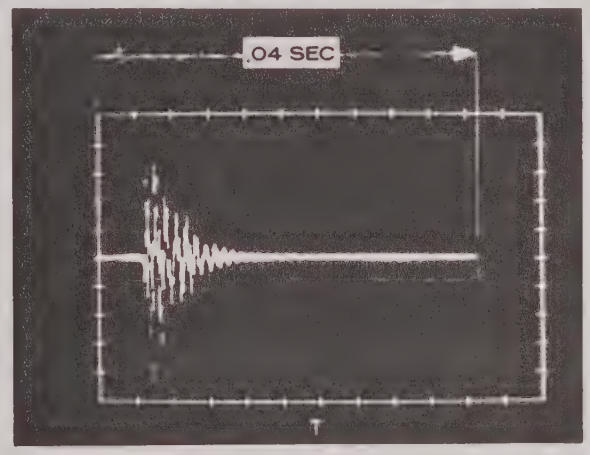

Figure 21. Waveform of captured transient.

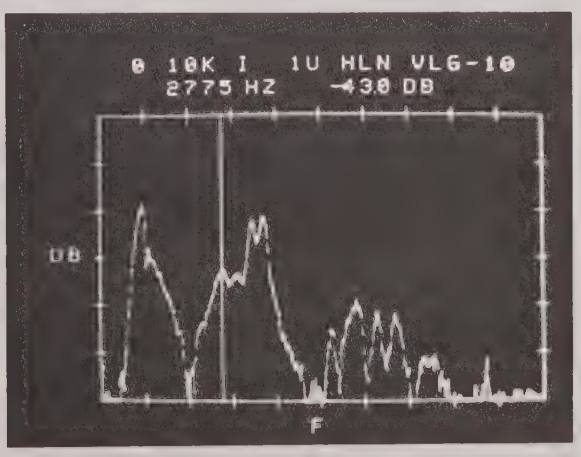

Figure 22. Spectrum of captured transient.

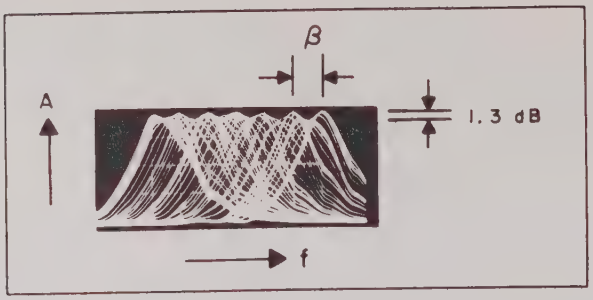

Figure 23. "Crack" between filters when using hanning weighting.

difficult to maintain amplitude linearities to within a few tenths of a dB from full scale to -40 dB of the analyzer output and to within 1 to 2 dB over an output range from -40 to -80 dB with respect to full scale.

Just like contiguous filters, FFT analyzers suffer from "cracks" between filter locations. If a sine wave coincides with the center frequency of one of the synthesized filters, its amplitude will be measured correctly. On the other hand, a sine wave which is located exactly midway between two filter locations will appear slightly lower in amplitude. Using hanning weighting, the "crack" between the filters is approximately 1.3 dB deep as shown in Figure 23.

In Figure 23 the vertical amplitude axis is linear and the oscillogram was obtained using multiple exposures as a sine wave was slowly moved in frequency over a few analyzer bandwidths, β.

Conclusions

Within seconds a high performance spectrum analyzer presents to an operator a picture of vibration, noise, or other data in terms of frequency content. A source of noise and vibration can frequently be located by its characteristic frequency signature. Changes in test conditions appear as changes in the distribution of frequencies...a screw tightened, a transducer relocated, a bearing aligned. The successful application of spectrum analysis techniques requires careful interpretation of spectrum data including consideration of possible sources of distortion and errors in such data.

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BITS, BYTES, AND BAUDS

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This paper will review common terms used in data communications and interfaces.

Data Communication - Communication between digital machines takes place via transmission of coded messages. These messages contain bits.

Bits - The bit is the smallest part of a coded message. The bit is a unit of information that has only two states (binary). These states may be on/off, high/low, true/false, current/no current, and so forth. Bits are put together to form a message. When the message is sent one bit at a time the message is bit serial.

Bit Serial - Bit serial communication is a simple form for data transmission. Transmission to an ASR 33 Teletype is in bit serial form.

Byte - When a group of bits is treated as a unit this unit is called a byte. Generally, a byte is defined as a group of 8 bits.

Bit Parallel, Byte Serial - When bytes are sent in serial form, the communication is sometimes referred to as bit parallel (one byte sent simultaneously), but byte serial (a byte at a time).

The IEEE 488 (HP-IB) interface is a bit parallel, byte-serial communication bus.

Baud (Data Rate) - In bit serial communication, the data rate or "baud rate" refers to the bit transfer rate of the channel.

Baud is a measure of bits per second, although technically it refers to events per second. Thus, if a system sends a character by 1 start bit + 7 data bits + parity + 2 stop bits, each character requires 11 bits. Thus, 110 baud = 10 characters per second.

Common baud rates are 110, 150, 300, 600, 1200, 2400, 4800, and 9600.

Simplex Transmission - Transmission in one direction only is called simplex transmission.

Half-Duplex - Bi-directional transmission, but only one way at a time, is called half-duplex. This type of transmission is common in low cost medium speed communication links.

Full-Duplex - Simultaneous communication in both directions is called full-duplex.

Synchronous Transmission - To increase the data rate, it is desirable to minimize the number of extraneous delineator bits (start/stop). In synchronous transmission, a separate line carries this information, usually indicating the start and end of a data block, rather than character by character.

Asynchronous Transmission - Here the delineator bits become part of the data stream allowing self-clocked transmission.

Codes - Information is transmitted by means of coded messages consisting of bits. Some common codes used in data transmission are straight binary, octal, hexadecimal, and ASCII.

Straight Binary - A straight binary transmission is a code representing a number. Thus, a two-bit binary code can have values from 0 to 3.

MSB - Most Significant Bit

LSB - Least Significant Bit.

MSB (2^1)	LSB (2^0)	
0	0	= 0
0	1	= 1
1	0	= 2
1	1	= 3

When strings become long it is difficult to read a number like 001010110101. Therefore, an octal code is sometimes used.

Octal - Octal breaks up a binary number into groups of three bits, starting at the least significant bit (LSB). Since 3 binary bits can have only states 0 to 7, it is easy to represent the number above as 1265.

$$\underbrace{001}_{1}\quad\underbrace{010}_{2}\quad\underbrace{110}_{6}\quad\underbrace{101}_{5}$$

Thus, a "decimal" number system is used to make it easy to work on longer binary numbers.

BCD - Binary coded decimal uses 4 binary bits to represent the decimal numbers 0 through 9. However, since 4 binary bits can represent numbers from 0 through 15, the codes 10 through 15 are illegal and cannot exist in BCD transmission. BCD is used in coding decimal switches, numeric readouts, etc.

Hexadecimal - In this code 4 bits also are used to define a character, but all states are allowed. The binary numbers from 0 through 9 are left as 0 through 9, 10 through 15 are represented by A$\rightarrow$F respectively.

Hexadecimal transmission is common because groupings by 4 are convenient. Also, it makes use of all the possible binary combinations (no illegal codes).

ASCII - The American Standard Code For Information Interchange (ASCII) is a 7-bit code for alphanumeric communication with an 8th bit added for parity check if used. The ASCII code is shown in Table 1.

Many terminals and transmissions use only part of the ASCII repertoire. For example, alphanumerics with upper case letters only is quite common.

Limited Use ASCII - Since most terminals recognize the ASCII code, it is quite often advantageous to use this code even in a limited capacity merely because it can be recognized. Thus, the 7-bit code can be used to send over only the octal code 0 through 7, or the hexadecimal code 0-9 and A - F. Although only three and four bits respectively are required for these two codes, the additional bits make the communication "universally" acceptable.

Table 1

ASCII CODE CHART

BITS B7 B6 B5 / B4 B3 B2 B1	Ø Ø Ø	Ø Ø 1	Ø 1 Ø	Ø 1 1	1 Ø Ø	1 Ø 1	1 1 Ø	1 1 1
	CONTROL		HIGH X & Y GRAPHIC INPUT		LOW X		LOW Y	
Ø Ø Ø Ø	NUL 0	DLE 16	SP 32	0 48	@ 64	P 80	\ 96	p 112
Ø Ø Ø 1	SOH 1	DC1 17	! 33	1 49	A 65	Q 81	a 97	q 113
Ø Ø 1 Ø	STX 2	DC2 18	" 34	2 50	B 66	R 82	b 98	r 114
Ø Ø 1 1	ETX 3	DC3 19	# 35	3 51	C 67	S 83	c 99	s 115
Ø 1 Ø Ø	EOT 4	DC4 20	$ 36	4 52	D 68	T 84	d 100	t 116
Ø 1 Ø 1	ENQ 5	NAK 21	% 37	5 53	E 69	U 85	e 101	u 117
Ø 1 1 Ø	ACK 6	SYN 22	& 38	6 54	F 70	V 86	f 102	v 118
Ø 1 1 1	BEL 7	ETB 23	' 39	7 55	G 71	W 87	g 103	w 119
1 Ø Ø Ø	BS 8	CAN 24	(40	8 56	H 72	X 88	h 104	x 120
1 Ø Ø 1	HT 9	EM 25	) 41	9 57	I 73	Y 89	i 105	y 121
1 Ø 1 Ø	LF 10	SUB 26	* 42	: 58	J 74	Z 90	j 106	z 122
1 Ø 1 1	VT 11	ESC 27	+ 43	; 59	K 75	[91	k 107	{ 123
1 1 Ø Ø	FF 12	FS 28	, 44	< 60	L 76	\ 92	l 108	¦ 124
1 1 Ø 1	CR 13	GS 29	- 45	= 61	M 77	] 93	m 109	} 125
1 1 1 Ø	SO 14	RS 30	. 46	> 62	N 78	^ 94	n 110	~ 126
1 1 1 1	SI 15	US 31	/ 47	? 63	O 79	_ 95	o 111	RUBOUT (DEL) 127

Parity

- A parity bit is used to afford some error detection capability in the transmission.

  Parity can be odd or even. When even parity is used, the sender counts the number of 1 bits in each character. If the total number of 1 bits is even (0,2,4,etc.), then the parity bit is made equal to binary 0 to keep the total even. If the total number of 1 bits is odd, the parity bit is made a binary 1 to restore the total number of 1 bits to an even number.

  Odd parity is the opposite of even. The sender makes the parity bit a 1 or zero to keep the total number of 1 bits transmitted odd.

RS-232C

- The Electronic Industries Association has defined a specification for the "Interface Between Data Terminal Equipment And Data Communication Equipment Employing Serial Binary Data Interchange". This specification is called the RS-232C standard. Basically, this specification prescribes the electrical characteristics of the signal and the type of connector (plus pin assignments) to be used. A 25-pin connector is used with each pin designated for a specific signal.

  The RS-232C is for serial bit communication and provides for single path (half-duplex) or dual path (full-duplex) operation.

  It <u>does not</u> spell out the code used in the transmission.

  Within the RSR-232C specification there are different subset specifications. Obviously, for simplex transmission, all the lines in the connector are not required. Therefore, the subset indicates which lines are used. For example, simplex transmission requires only Type A.

	PIN	SIGNAL	
	7	AB	Signal Ground
	2	BA	Transmitted Data
	5	CB	Clear to Send
	6	CC	Data Set Ready

The Mini-Ubiquitous® Model 444, RS-232C, is a half-duplex interface, Type D, using a request-to-send and a clear-to-send signal.

WHAT RS-232C Is Not

- Although 2 devices may be built to the same RS-232C and interface subset, they may still not be able to communicate with each other because

  1. Format of data is different.
  2. Speed and timing are incompatible.

IEEE 488 (GP-IB) (HP-IB)

The new IEEE 488 standard also called General Purpose Interface Bus (GP-IB) is essentially the HP-IB.

It is a bit parallel-byte serial interface. The byte consists of 8 bits.

Eight bidirectional lines are provided to communicate with other devices. These lines can transfer data as well as address information.

Eight additional "housekeeping" lines provide control information. Three of these lines are for handshake signals. The remaining five are for general management.

Basically, the interface operates in one of two major modes. First is the setup mode. This mode establishes which devices will be on the line,(listeners) and which device will supply the data, talker. After the bus has been set up, the second or data transmission mode follows.

The data transmission mode is a complete handshake interface; that is, each byte transmission must be acknowledged by the listener.

The standard specifies the type of connector (24 pin) and the signal characteristics (TTL).

Because data is sent bit parallel-byte serial, the speed of this interface is much higher than the bit serial communication.

Again, the format of the data going over the 8 lines is not specified and can be binary, ASCII, etc.

Thus, similar to the RS-232C standard, the IEEE 488 is a black-box to black-box external type interface.

CAMAC (IEEE 583)

- Another standard widely used in the nuclear physics field and also process control is the CAMAC or IEEE 583 standard.

This standard specifies not only the data lines, but also the type of housing and modules used. All CAMAC users must fit their system into specified boxes, "crates". These have module cards and shielding. Also, each crate has a controller card. The crate or card cage is terminated in an 86-pin connector..

The bus is a wide parallel bus. Over 1000 different modules have been designed for this interface, many available from 2nd and 3rd sources.

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